Investigations in Nucleon Spin Structure: From [($e/\mu+p$) to] $p+p$ to $e+p$

Comment on the physics of pA/eA at the end

RHIC AGS Users Meeting
June 17, 2014
Nucleon Spin Structure Workshop

Stony Brook University | The State University of New York

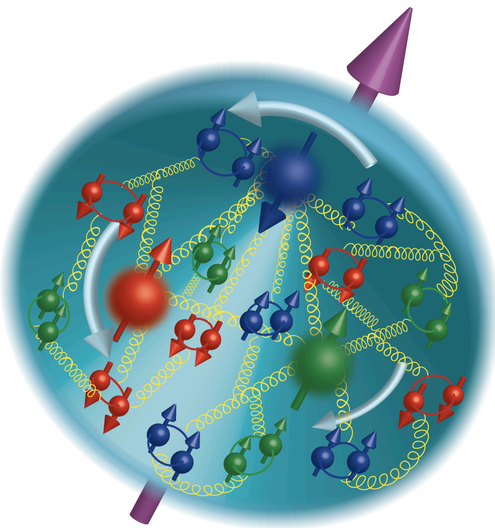
Abhay Deshpande

Outline

Significance of "spin" in nature

Nucleon Spin Problem

- "Spin" before RHIC Spin
- RHIC Spin Program
  - Impact
- Beyond RHIC Spin
  - Spin physics at the EIC



Spin always leads to surprises…

Some spin surprises in physics

- Stern Gehrlach (1921)

  Space quantization associated with direction
- Goudschmidt & Uhlenbeck (1926)

  Atomic fine structure and electron spin magnetic moment
- Stern (1933)

  Proton anomalous magnetic moment $\mu_p = 2.79$
- Kusch (1947)

  Electron anomalous magnetic moment $\mu_e=1.00119$
- Yale-SLAC Collaboration (Prescott & Hughes et al., 1978)

  Electro-Weak interference in polarized e-D: parity non-conservation
- European Muon Collaboration (1989)

  The proton spin crisis

- It could be effectively argued that the 20th century was a

Century of Spin Surprises

In fact, it has been said by various **theorists:**

“*Experiments with “spin” have killed more theories than any other single physical property”* *E. Leader*

“*If theorists had their way, they would ban all experiments with spin”* *J.D.Bjorken*

Spin is useful: not just in particle and nuclear physics…. But also in every day life

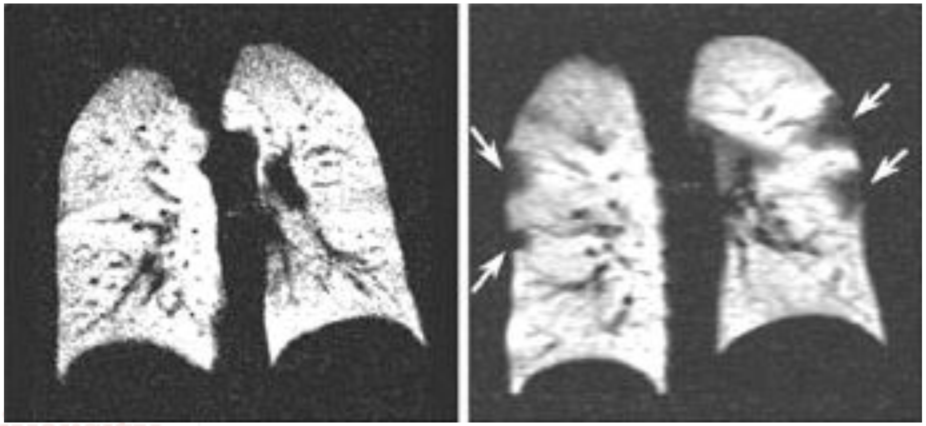
Investigations of nucleon spin composition in particle & nuclear physics, directly led to the following innovation and application!

Applications of Spin ½ … MRIs

H-MRI of the chest, black area: Lungs

^{3}He-MRI Lung is visible in detail

Non Smoker

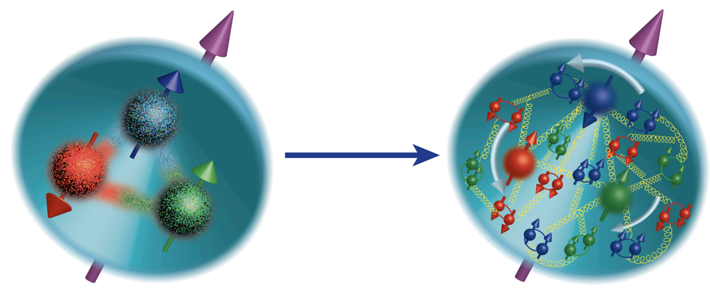


Smoker
Arrows: ventilation defects

Prof. Werner Heil, Institute of Physics, Johannes Gutenberg University

Spin is important for physics and useful but… despite decades of study, we don't quite understand it!

Our Understanding of Nucleon Spin vs. Time



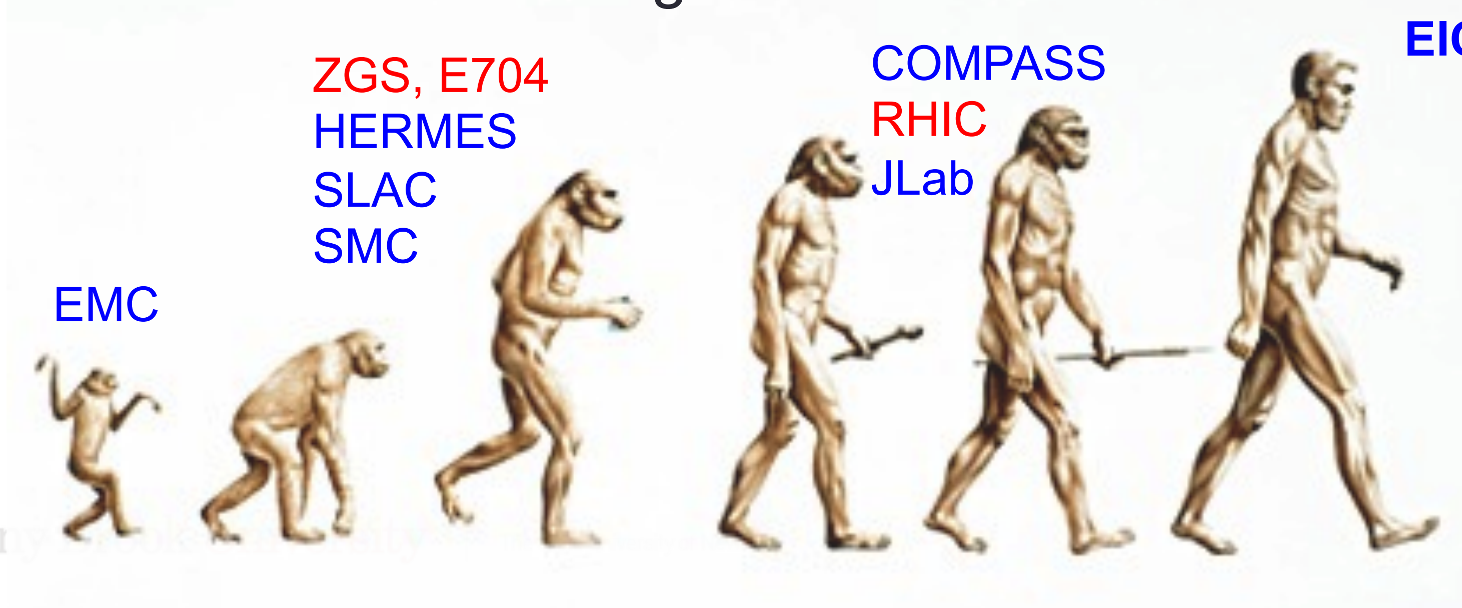
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{Q,G}$$

$\Delta\Sigma$ = Quark + anti-quark helicity contribution to nucleon spin

L_Q = Orbital motion of the quarks

ΔG = Gluon helicity contribution to the nucleon spin

L_G = Orbital motion of the gluons



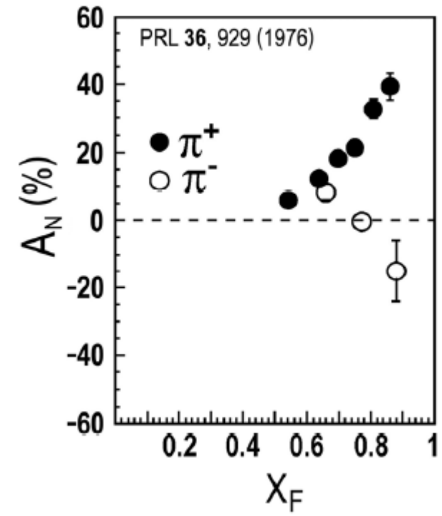
Before RHIC Spin:

Two distinct and *unconnected* research streams:

a) Transverse polarized p-p scattering (1970's)

b) Deep inelastic scattering (1980s)

Transverse spin asymmetries in p-p scattering:



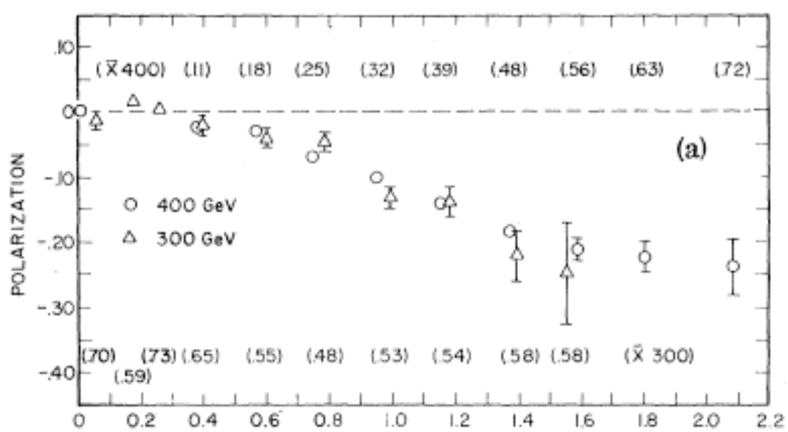
Significant asymmetries seen at low energies

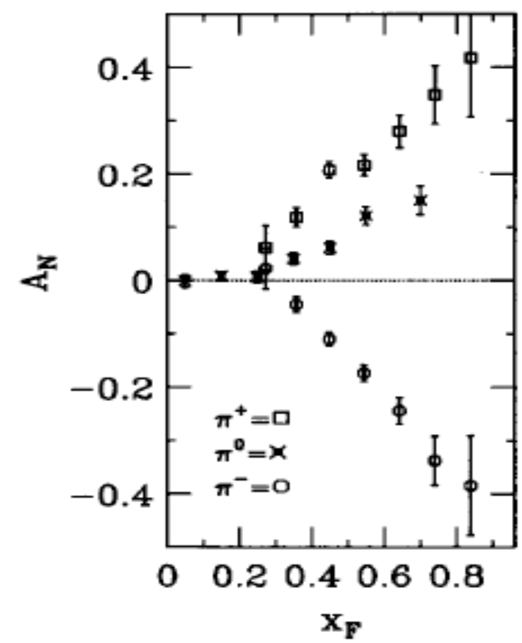
Results from ZGS and AGS

Transverse spin effect expected to be small at high energies… but from FNAL came two surprises…

Lambda (and other hyperon's) polarization

Asymmetries in inclusive pion production E704

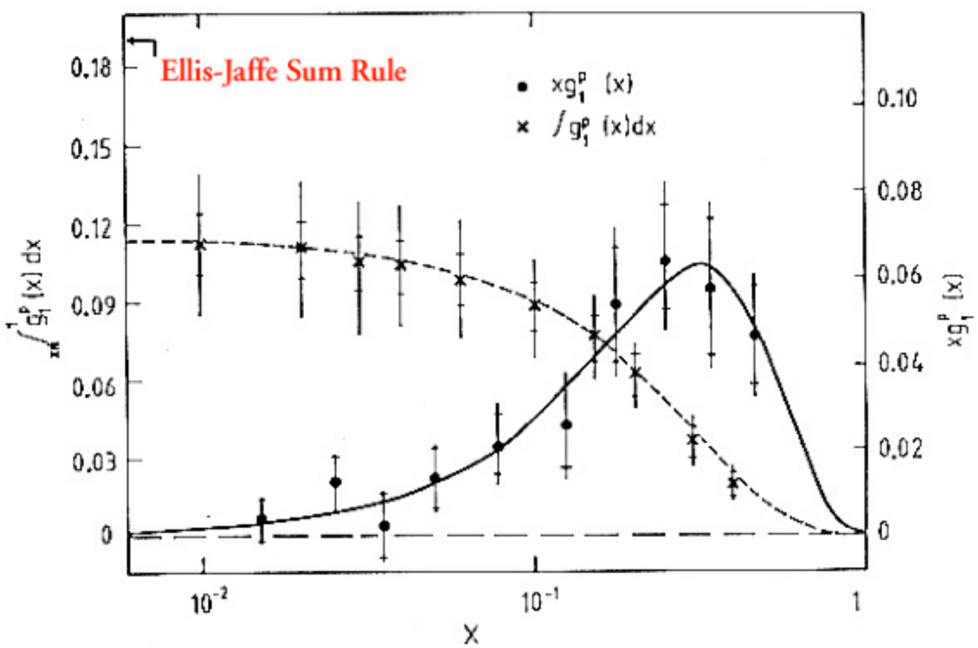


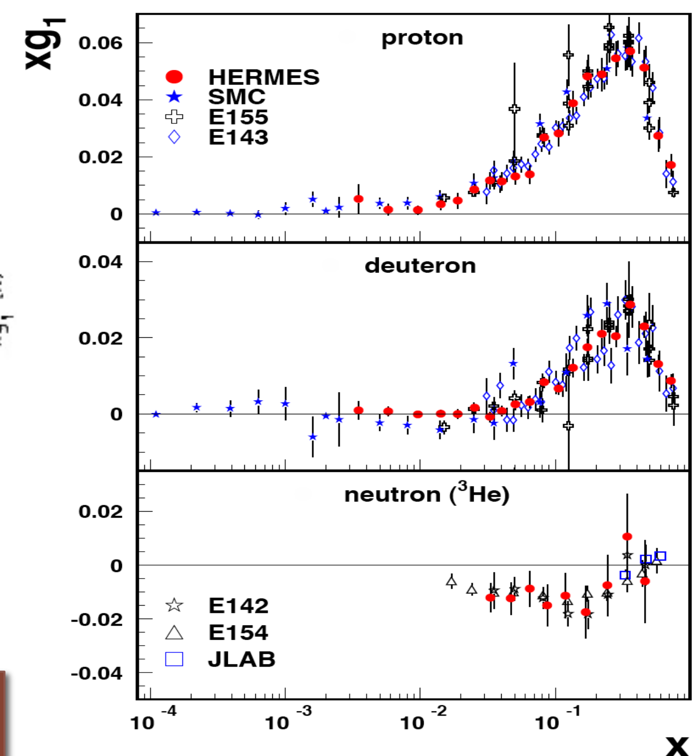


Deep Inelastic Scattering: The Spin Crisis

Quarks carry only about 25% of the nucleon spin

What carries the remaining spin of the proton?





Strong suggestion → Glue !

Aftermath of EMC Spin Crisis

Naïve quark model: ½ = $\Delta\Sigma/2$, where $\Delta\Sigma = 1$, from and $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ ➔ Relativistic effects bring $\Delta\Sigma \sim 0.6$, but

➔ we found $\Delta\Sigma \sim 0.46$

If quarks don't carry the nucleon spin: who does? Gluons and possible orbital motion of quarks and gluons!

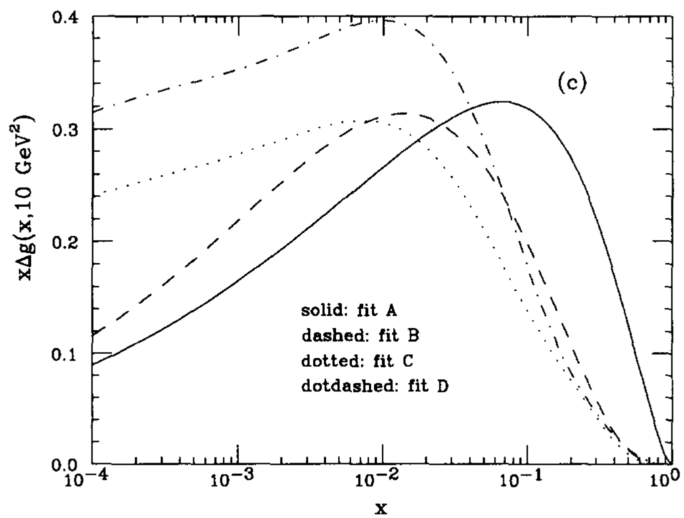
$$\Delta\Sigma(Q^2) = \Delta\Sigma' - N_f \frac{\alpha_S(Q^2)}{2\pi} \Delta g(Q^2)$$

Altarelli & Ross
Carlitz & Collins
Mueller et al.

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{Q,G}$$

High expectations from ΔG

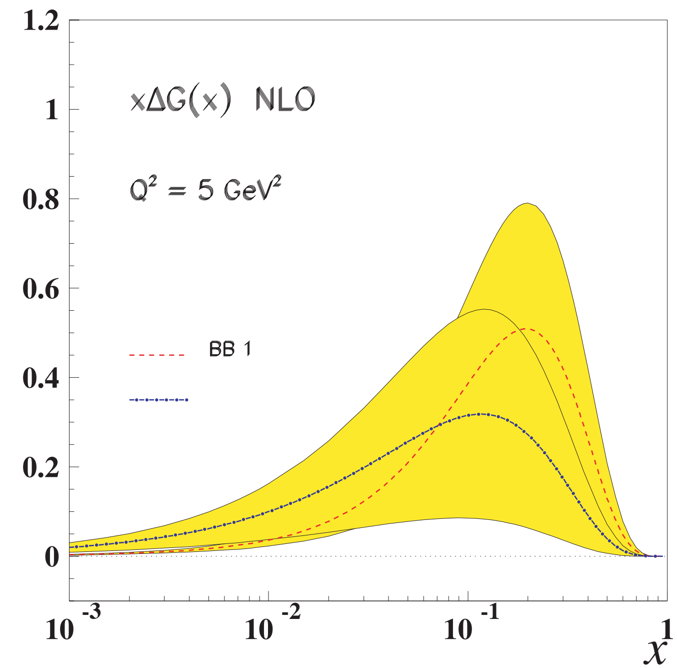
Altarelli et al. NP B 496 (1997) → NLO pQCD analysis of inclusive DIS in AB scheme



$$\Delta\Sigma(1) = 0.45 \pm 0.04\ (\mathrm{exp}) \pm 0.08\ (\mathrm{th}) = 0.45 \pm 0.09,$$

$$\Delta g(1, 1\ \mathrm{GeV}^2) = 1.6 \pm 0.4\ (\mathrm{exp}) \pm 0.8\ (\mathrm{th}) = 1.6 \pm 0.9,$$

$$a_0(\infty) = 0.10 \pm 0.05\ (\mathrm{exp})\ {}^{+0.17}_{-0.10}\ (\mathrm{th}) = 0.10\ {}^{+0.17}_{-0.11},$$



Blumlein et al. NP A721 (2003)
→ NLO pQCD in MSbar Scheme:
ΔG at Q^2=4 GeV^2 ~ 1.0 +/- 0.7

Also see: PRD 58 112002 (1998) for detailed discussion uncertainties

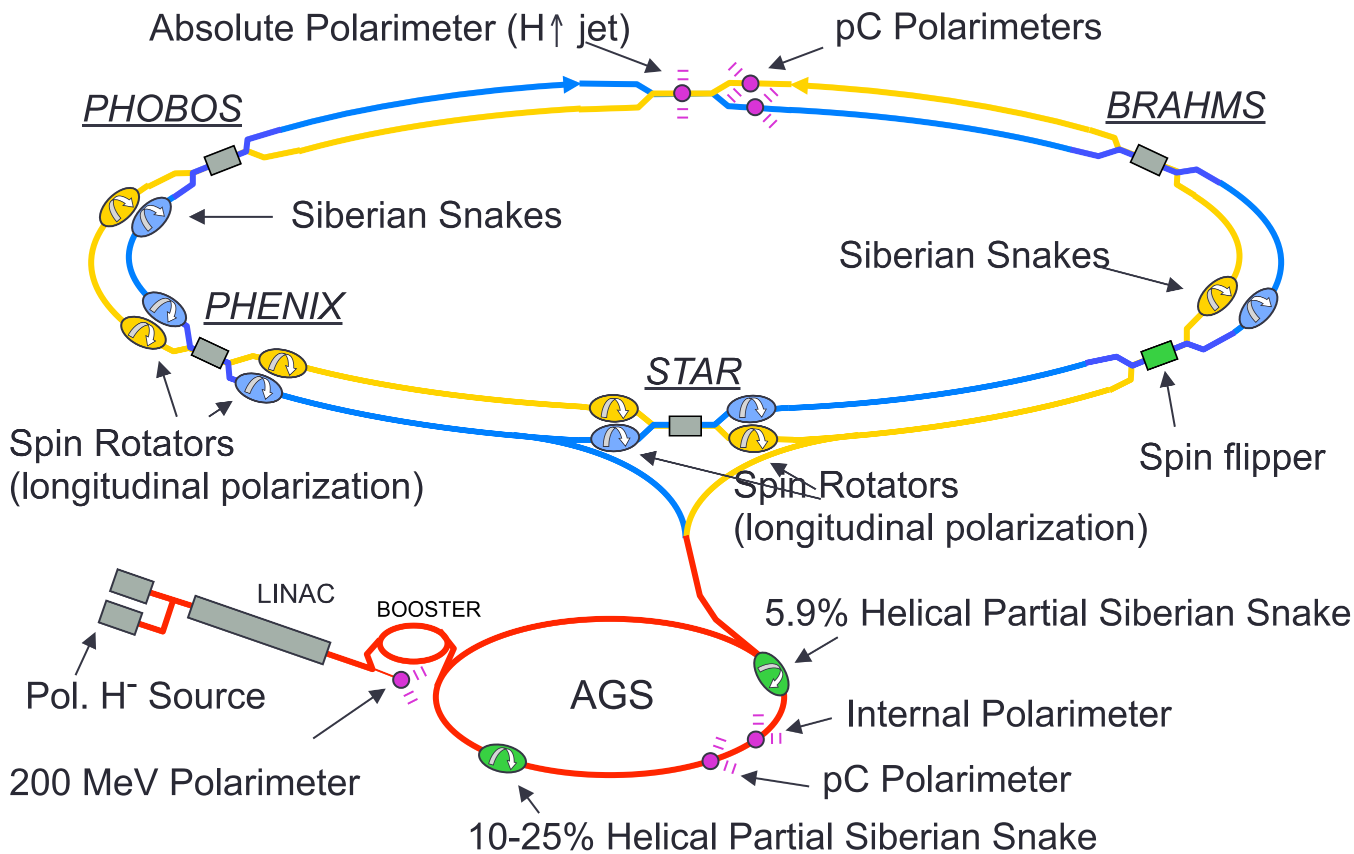
Motivation for RHIC Spin:

- If gluons really carry the bulk of nucleon's spin, why not use polarized proton (known by then to be predominantly made of gluons!)?
  - Technical know-how (Siberian Snakes, Spin Rotators, polarimetry ideas) to do this at high energy evolved around the time (mid/late-1990s)

- Why $\Delta\Sigma$ (quark + anti-quark's spin) small? Are quark and anti-quark spins anti-aligned? Polarized *p*+p at high energy, through W+/- production could address this

- A severe need for investigations of the surprising transverse spin effects was naturally possible and needed with the proposed polarized p+p collider…

RHIC as a Polarized Proton Collider

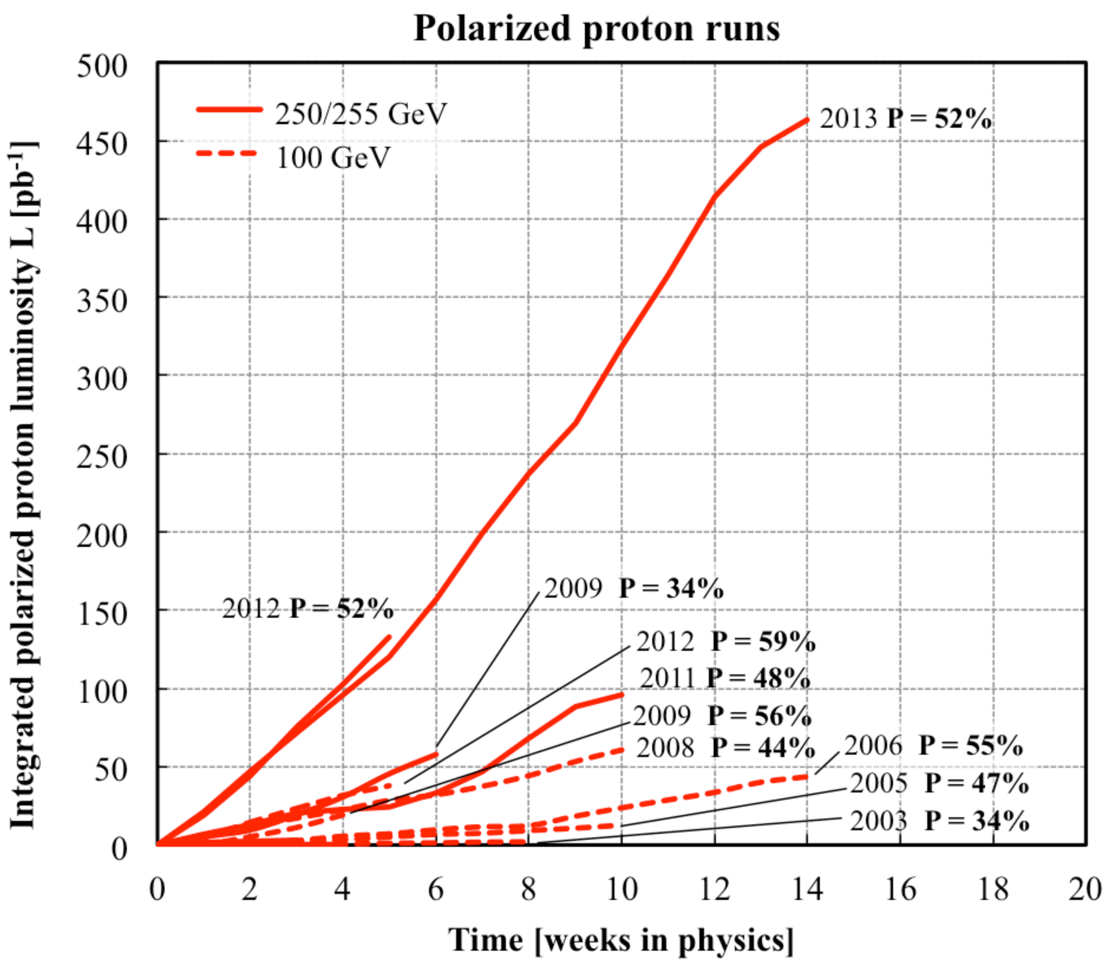


Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79\ E/m \rightarrow$ ~1000 depolarizing resonances
With Siberian snakes (local 180° spin rotators): $\nu_{sp} = ½ \rightarrow$ no first order resonances
Two partial Siberian snakes (11° and 27° spin rotators) in AGS

Polarized RHIC: A very big deal

- High current polarized proton source (OPPIS)
- Ability to accelerate polarized protons with Siberian Snakes demonstrated, and became a routine, at the highest energy!
- Ability to manipulate spin direction(spin rotator) and monitor that, demonstrated and became a routine.
- 106 ns bunch crossing with pre-determined spin directions a major boon for controlling systematics

RHIC polarized collider: a success!



Runs 4,5,6 & 9 with 100 GeV beams

- ΔG, transverse spin

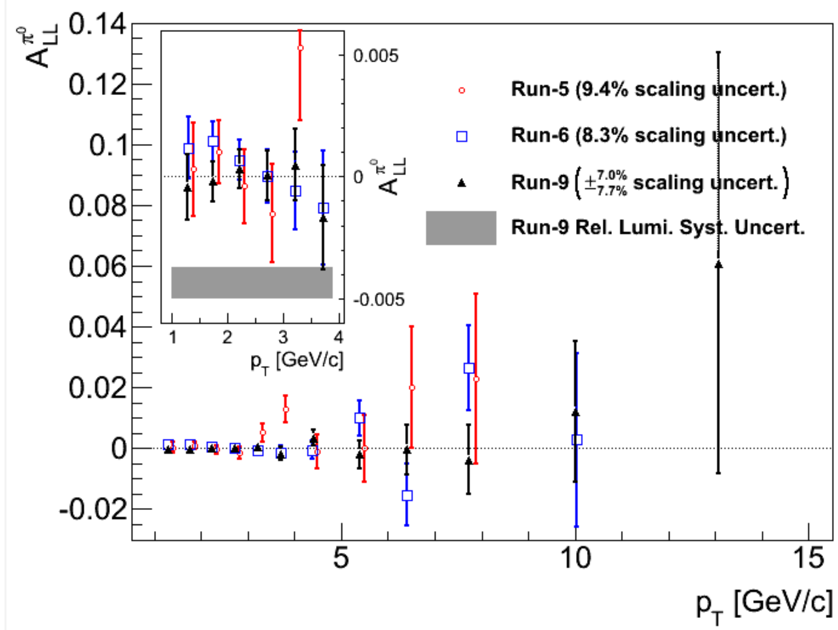
Runs 9,11,12, 13 with 250 GeV beams

- ΔG, W-Physics

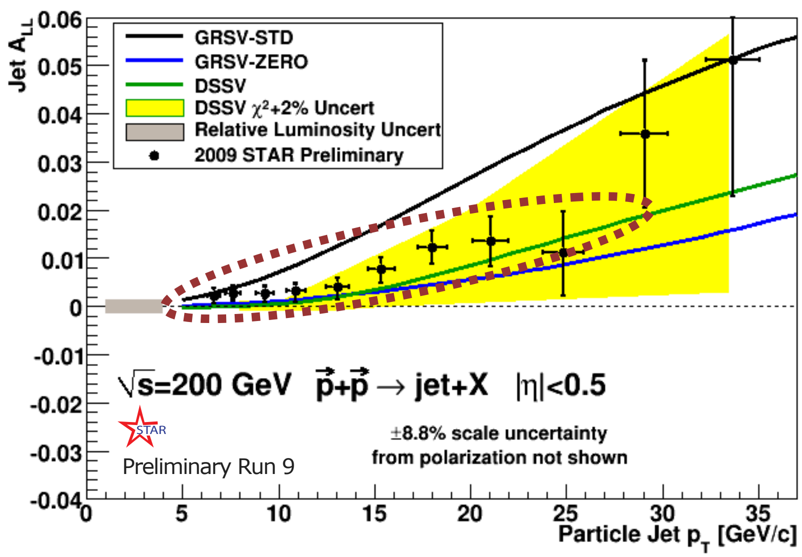
See experimental and theoretical talks in this session for details of various results & their interpretations

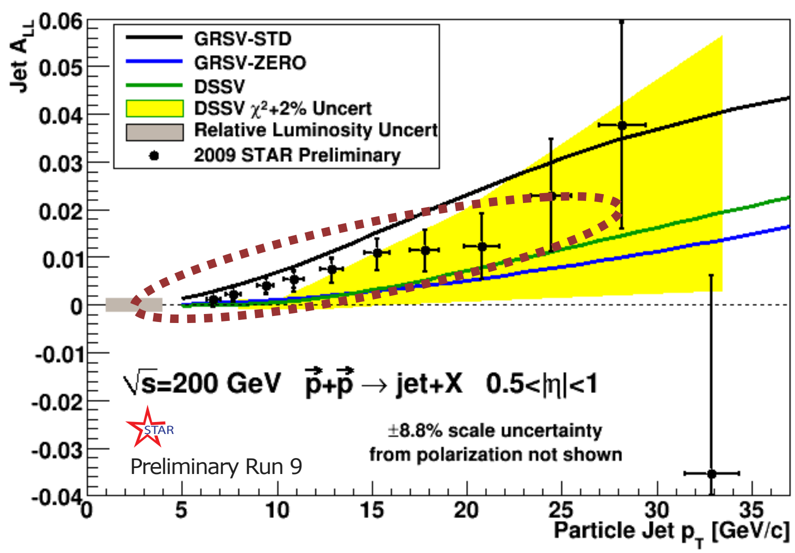
Most impactful results: on ΔG

- Inclusive probes
- Many others but highest impact with π^0 and jets
- Have been used in recent NLO pQCD analyses
- Experimental & theory systematic uncertainties have largely been downplayed.. This is an opportunity for near term improvement (Manion's talk)



A. Manion for PHENIX



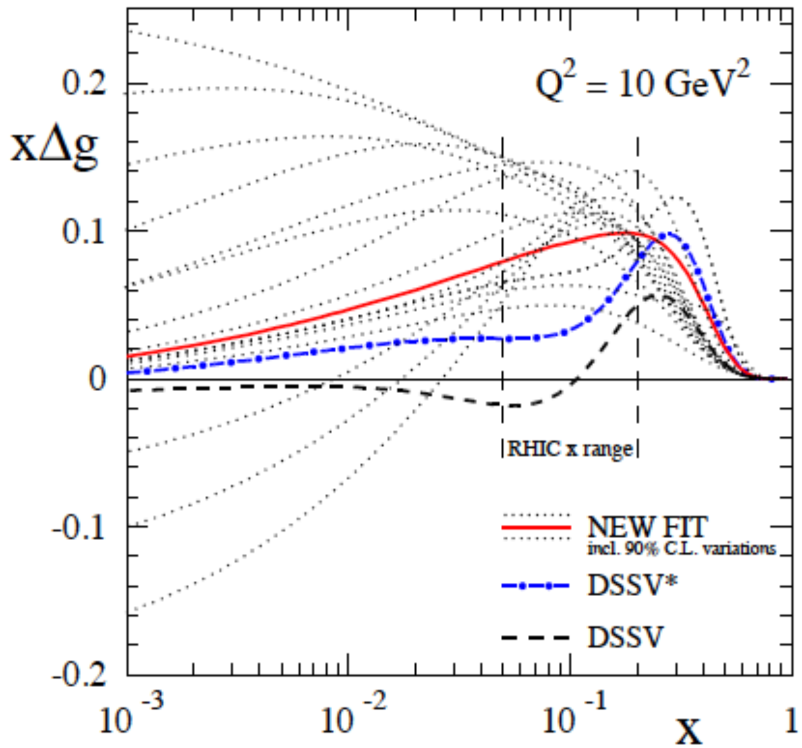


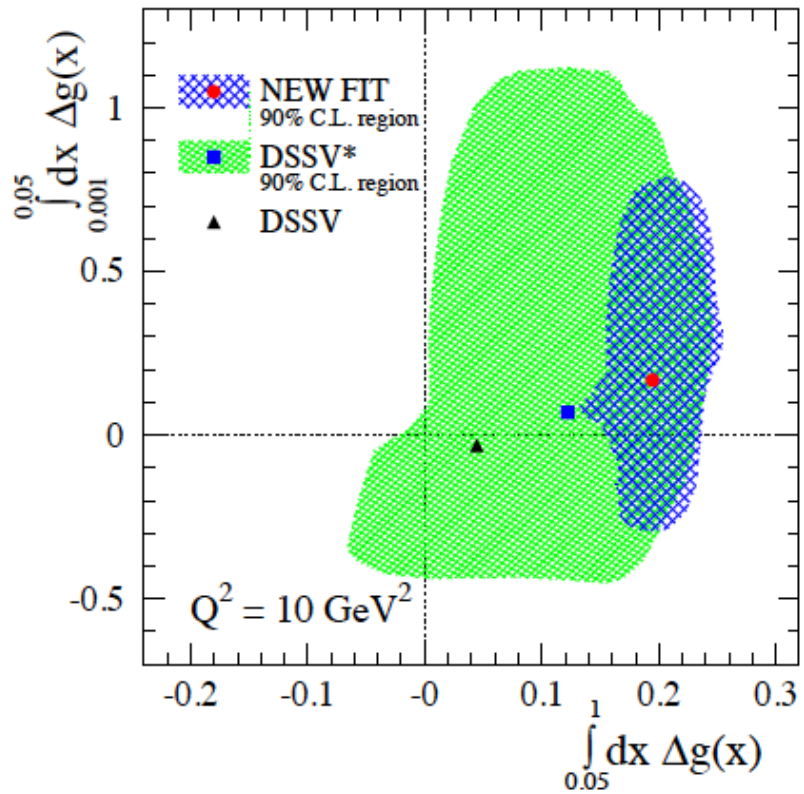
B. Surrow for STAR at DIS2014

Recent global analysis: DSSV

D. deFlorian et al., arXiv:1404.4293

Wide spread at low x (x<0.05) of alternative fits consistent within 90% of C.L.



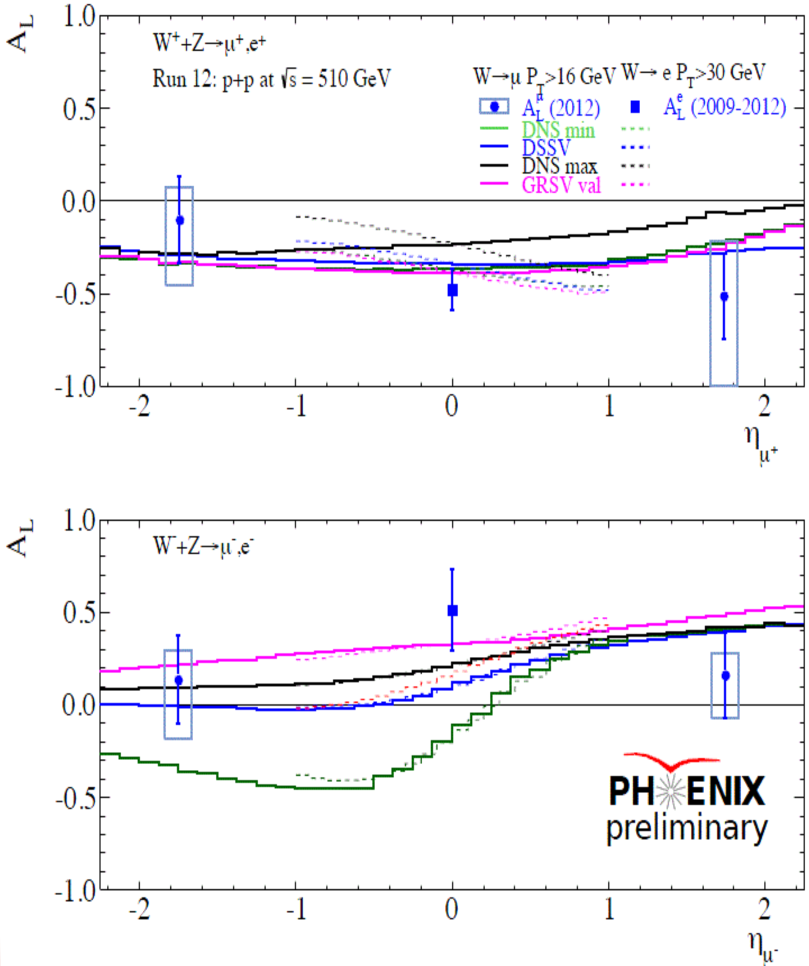


Dramatically makes the statement that, while we have made a huge impact, We are improving ΔG contributions only in a limited x-region, allowing large uncertainties to remain in the low-x unmeasured region!

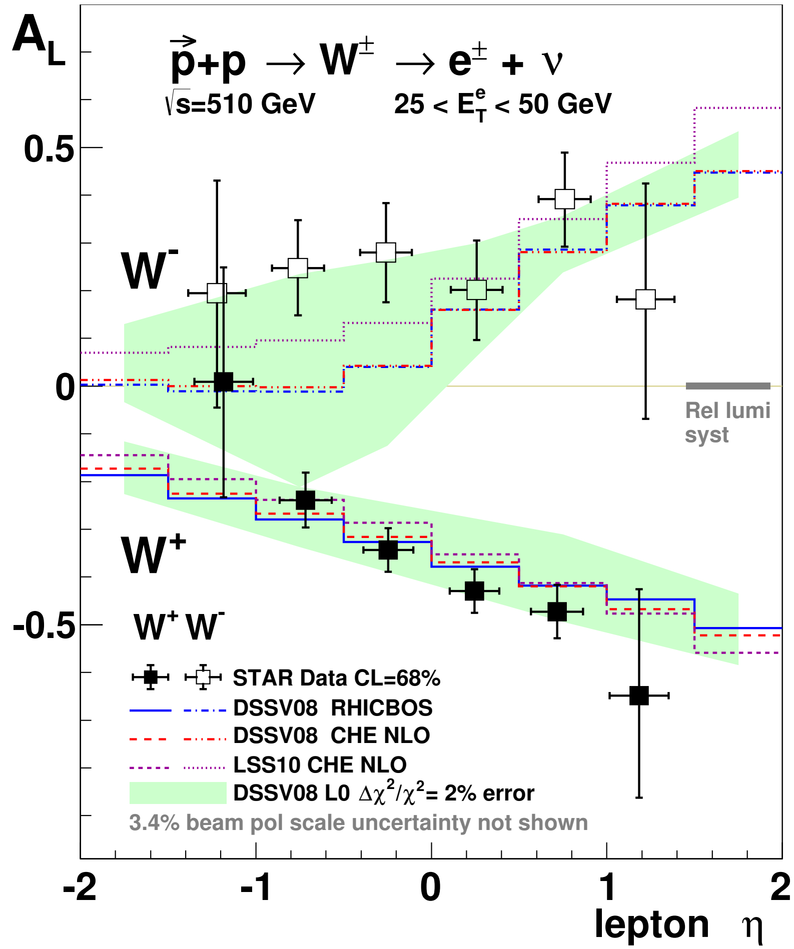
➔ *Forward rapidity in jets and π^0 may be useful but far from "game over"*

Recent results from RHIC: W→ $e^{+/-}, \mu^{+/-}$

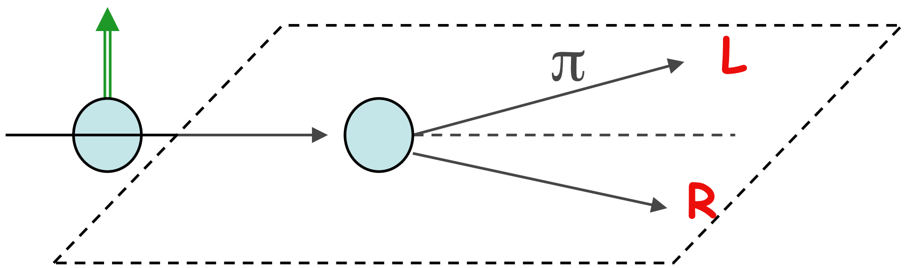
N Bandara for PHENIX



arXiv:1404.6880 STAR



Transverse spin introduction



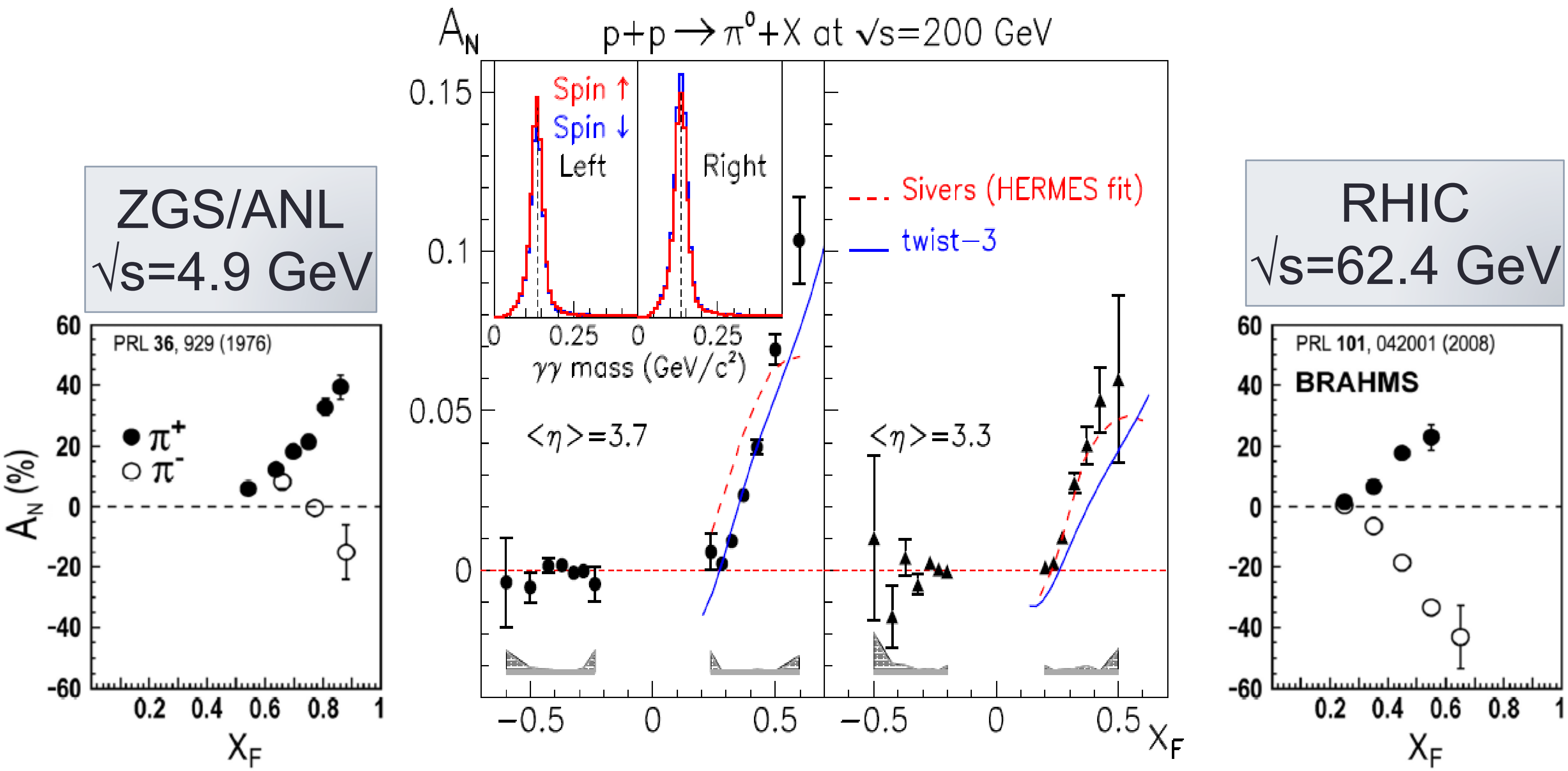
$$A_N = \frac{N_L - N_R}{N_L + N_R}$$

$$A_N \approx \frac{m_q \alpha_S}{p_T} \approx 0.001$$

Kane, Pumplin, Repko
PRL 41 1689 (1978)

SSA in hard scattering expected to be small, but large effects observed in pion & (recently) neutron production..

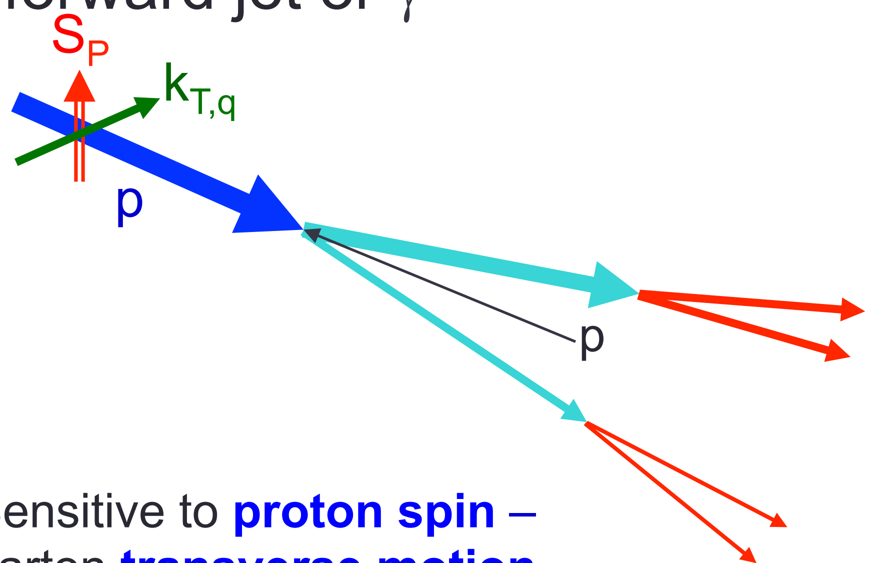
Pion asymmetries: at most CM energies!



Suspect soft QCD effects at low scales, but they seem to remain relevant to perturbative regimes as well

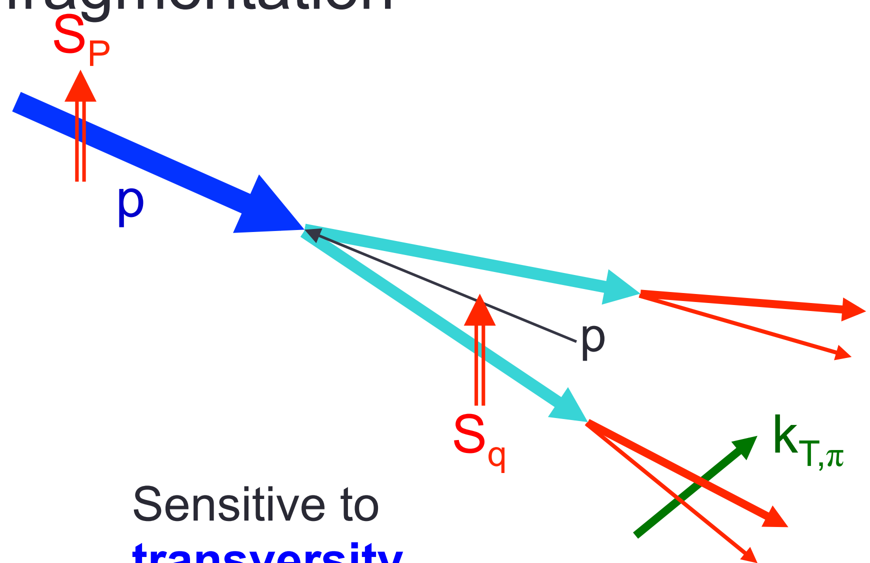
Possible origins for A_N

Sivers mechanism:
asymmetry in production of forward jet or γ



Sensitive to **proton spin – parton transverse motion** correlations

Collins mechanism:
asymmetry in the forward jet fragmentation



Sensitive to **transversity**

- **Need to go beyond inclusive hadron measurements** 2015 and beyond.
- Possibilities include jets, direct photons, di-hadron correlations, W-production… etc. addressing host of interesting issues including fundamental tests of QCD

Emergent picture of the nucleon:

RHIC has definitively shown that in $x > 0.05$, the GLUON's spin contribution to nucleon is small. Future facility should aim to make precise measurements at lower x.

RHIC seems to shown that quark anti-quark polarized PDFs are broadly consistent with expectations from SIDIS (not in violent disagreement!), early concerns about not knowing the fragmentation functions, possible higher twist and other complications of SIDIS: not a big concern.

Transverse spin in RHIC is quite possibly the best laboratory to test our understanding of QCD: Needing data and their understanding from e-p, e-e and theory to test if they can predict or explain the p-p: Jury is out on this, as it is an on-going effort with current and future forward physics/detector upgrade plans.

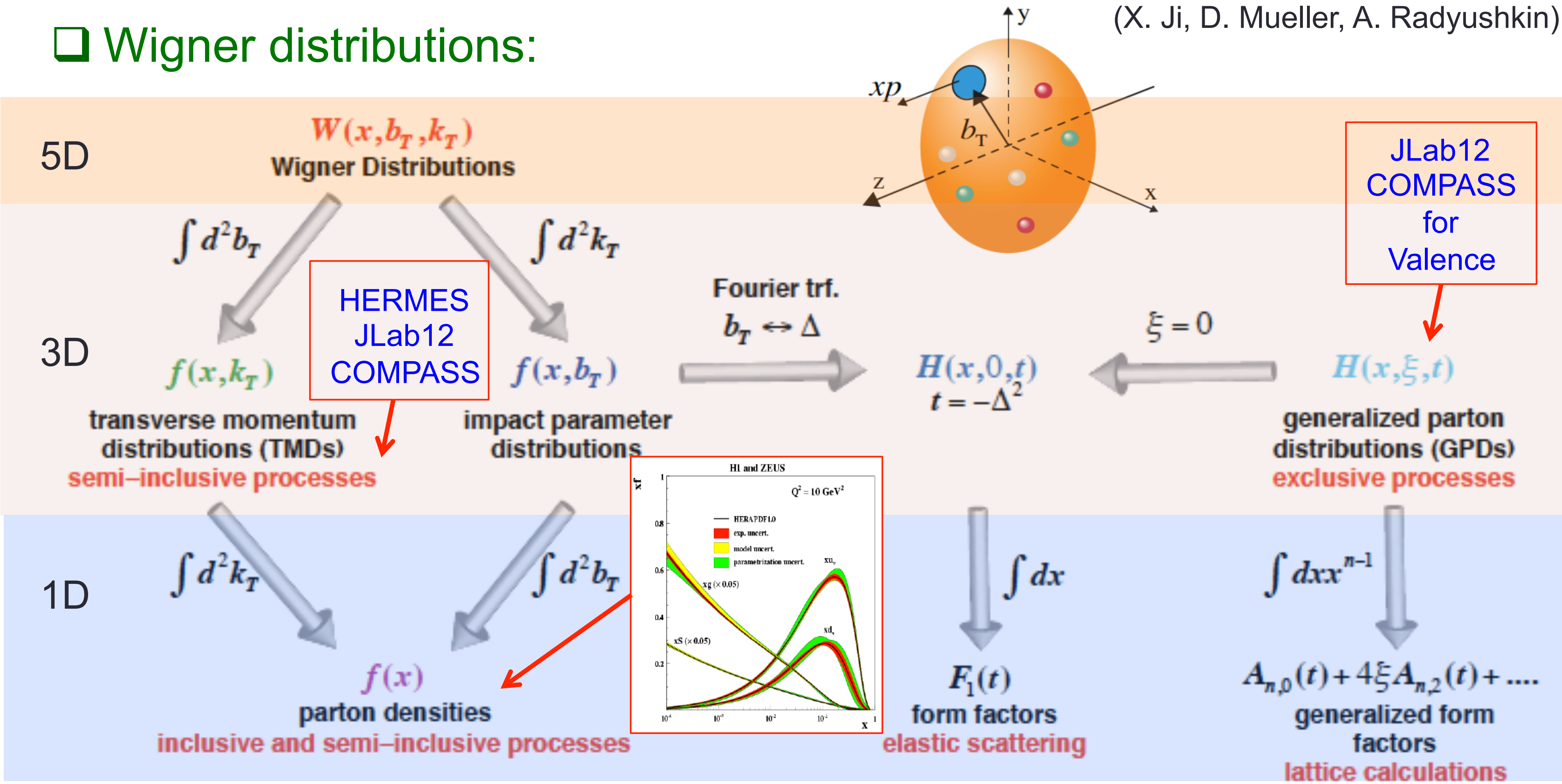
But a more complete picture of the nucleon structure including its spin has emerged over ….

Aided by theoretical developments & data from fixed target polarized DIS at COMPASS & JLab and p-p at RHIC experiments

We aspire to complete this unified picture of the nucleon structure and the parton dynamics

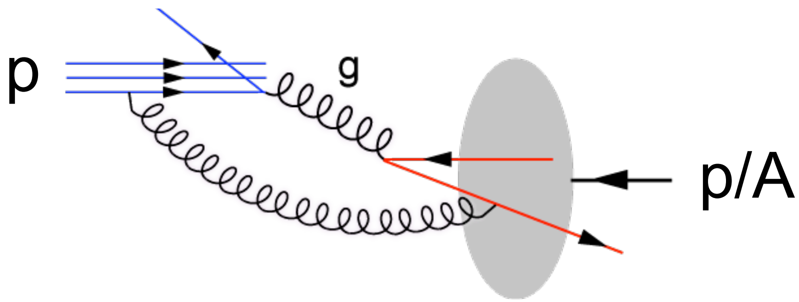
Unified view of the Nucleon Structure

- ❑ Wigner distributions:



- ❑ EIC – 3D imaging of partons: Quarks (fixed target) , Gluons (collider)
  - ✧ TMDs – confined motion in a nucleon (semi-inclusive DIS)
  - ✧ GPDs – Spatial imaging of quarks and gluons (exclusive DIS)

Hadron-Hadron

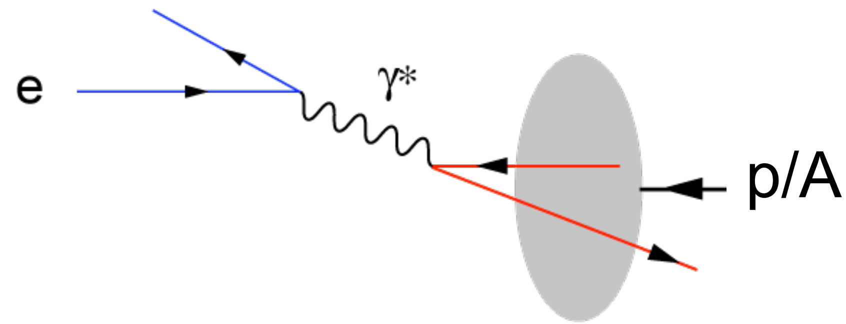


Probe & target complex

Soft interactions before collisions can destroy factorization, i.e. nuclear wave function affected

Kinematics imprecisely determined

Electron-Hadron (DIS)



Probe point like

No initial state soft interactions, factorization preserved

Kinematics precisely determined

Why a collider?

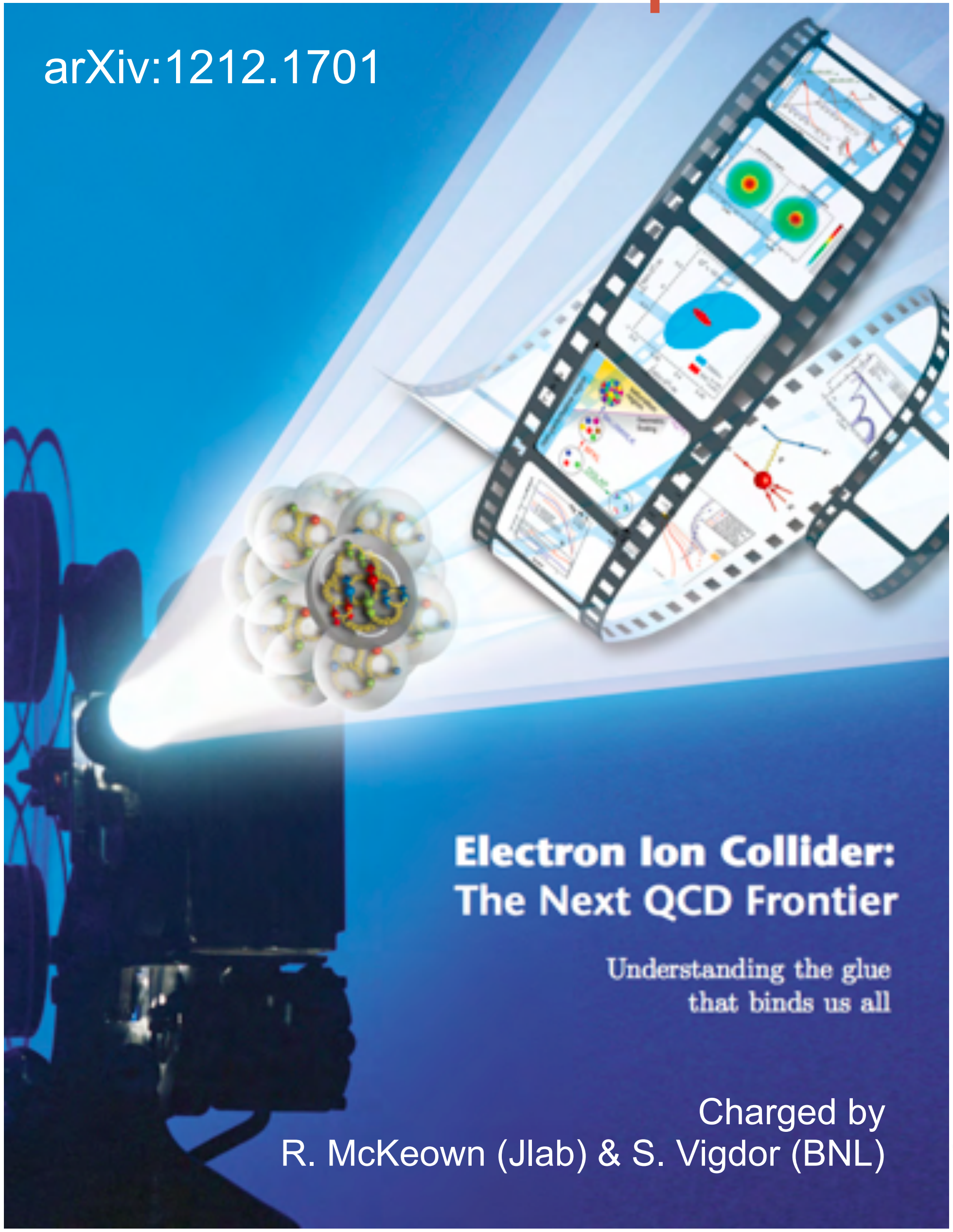
- A collider brings a very wide kinematic range in the observables in their measurable coordinates

- A high energy collider brings access to low-x and high Q^2
  - Low x ➔ largest uncertainties since no spin measurements there
  - Large Q^2 ➔ large arms to see and test Q^2 evolution in variables

- Compared to solid state fixed target experiments, the target and beam fragments in a collisions fly in different directions

- Rapid "target" and "beam" spin "flips" helps brings experimental systematics under control

White Paper: EIC Science Case



Overall Editors:
A. Deshpande (Stony Brook), Z-E. Meziani (Temple), J. Qiu (BNL)

Gluon Saturation in e+A:
T. Ullrich (BNL) and Y. Kovchegov (Ohio State)

Nucleon spin structure (inclusive e+N):
E. Sichtermann (LBNL) and W. Vogelsang (Tübingen)

GPD's and exclusive reactions:
M. Diehl (DESY) and F. Sabatie (Saclay)

TMD's and hadronization and SIDIS:
H. Gao (Duke) and F. Yuan (LBNL)

Parton Propagation in Nuclear Medium:
W. Brooks (TSFM) and J. Qiu(BNL)

Electroweak physics:
K. Kumar (U Mass) and M. Ramsey-Musolf (Wisconsin)

Accelerator design and challenges:
A. Hutton (JLab) and T. Roser (BNL)

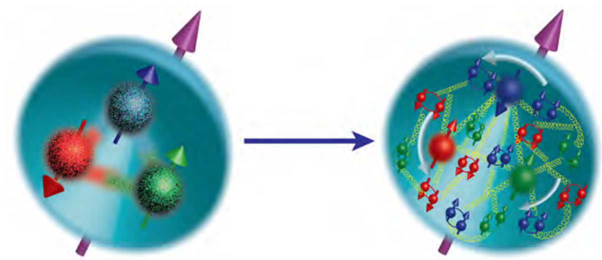
Detector design and challenges:
E. Aschenauer (BNL) and T. Horn (CUA)

Senior Advisors:
A. Mueller (Columbia) and R. Holt (ANL)

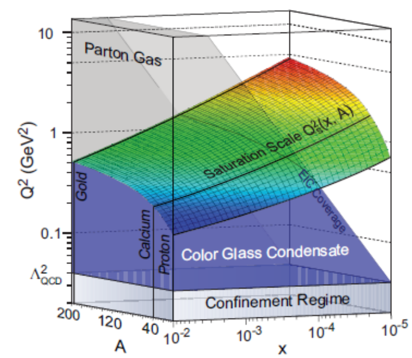
Successful thanks to many other co-authors and contributions

EIC – The Physics Highlights

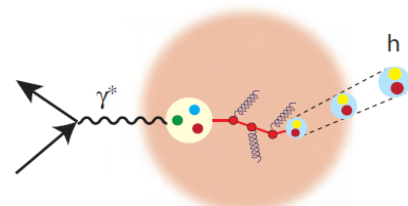
- **Explore and image the spin and 3D structure of the nucleon**
  Needs a machine with high polarized luminosity and variable energy range to cover valence to sea quarks and gluons, excellent acceptance/PID in detectors



- **Discover the role of gluons in structure and dynamics**
  Needs a machine capable of high energy capable of accelerating nuclei



- **Understand the emergence of hadrons from color charge**
  Needs machine capable of accelerating large & small nuclei & special detectors for nuclear fragments

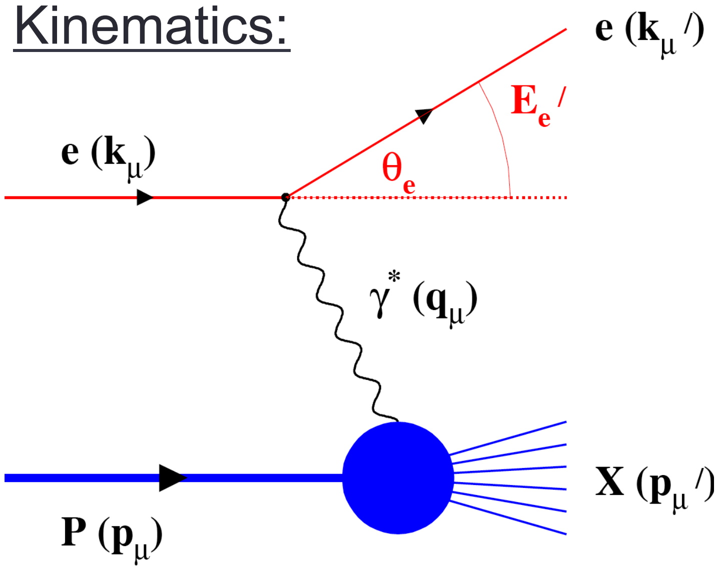


- **Investigations of physics beyond the Standard Model**

Highest e-p luminosity, highest possible energy and at least one beam polarization

Deep Inelastic Scattering = Precision + Control

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

Measure of resolution power

$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

Hadron :

$$z = \frac{E_h}{\nu};\ p_t \text{ with respect to } \gamma$$

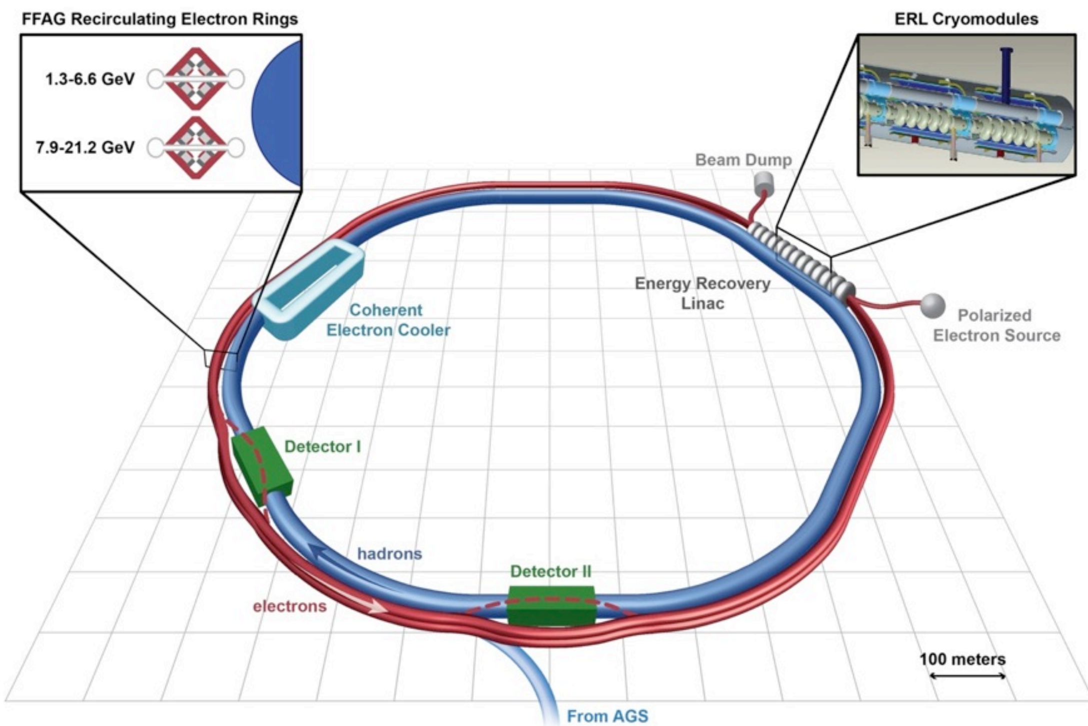
Inclusive events: e+p/A → e'+X
detect only the scattered lepton in the detector

Semi-inclusive events: e+p/A → e'+h(π,K,p,jet)+X
detect the scattered lepton in coincidence with identified hadrons/jets in the detector

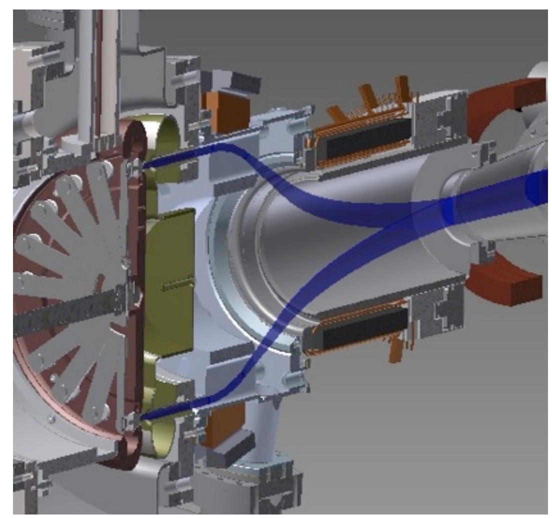
Exclusive events: e+p/A → e'+ p'/A'+ h(π,K,p,jet)
Detect every things including scattered proton/nucleus (or its fragments)

eRHIC Machine Design

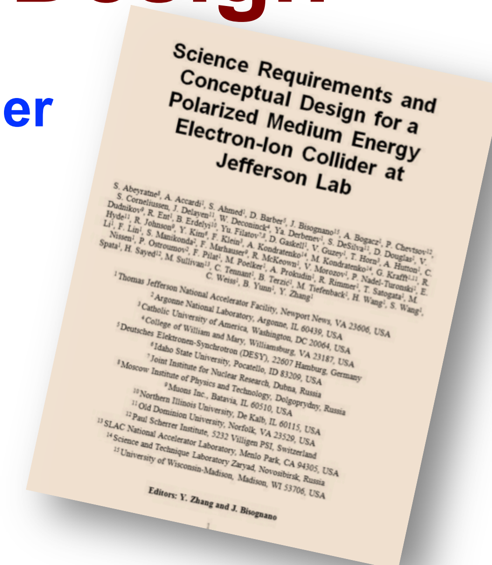
- ✓ Up to 21.2 GeV electron beam accelerated with Energy Recovery Linac (ERL) inside the RHIC tunnel collides with existing 250 GeV polarized protons and 100 GeV/n HI RHIC beams
- ✓ ERL with 1.32 GeV SRF Linac and two FFAG recirculating rings (1.33 – 6.62 GeV; 7.94 – 21.16 GeV) allow for full luminosity (> 10^{33} cm^{-2} s^{-1}) up to 15.9 GeV and reduced luminosity up to 21.2 GeV
- ✓ Single collision of each electron bunch allows for large disruption ➔ high luminosity and full electron polarization transparency
- ✓ *Accelerator R&D for highest luminosity: High current (50 mA) pol. electron gun (Gatling gun); High average current ERL with FFAG passes; Coherent electron cooling of hadron beam*



50 mA polarized electron gun (Gatling gun)



MEIC at JLab: Conceptual Design


Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-Ion Collider at Jefferson Lab

S. Abeyratne[8], A. Accardi[1], S. Ahmed[1], D. Barber[5], J. Bisognano[15], A. Bogacz[1], P. Chevtsov[12], S. Corneliussen, J. Delayen[11], W. Deconinck[4], Ya. Derbenev[1], S. DeSilva[11], D. Douglas[1], V. Dudnikov[9], R. Ent[1], B. Erdelyi[10], Yu. Filatov[7,8], D. Gaskell[1], V. Guzey[1], T. Horn[3], A. Hutton[1], C. Hyde[11], R. Johnson[9], Y. Kim[6], F. Klein[3], A. Kondratenko[14], M. Kondratenko[14], G. Krafft[1,11], R. Li[1], F. Lin[1], S. Manikonda[2], F. Marhauser[9], R. McKeown[1], V. Morozov[1], P. Nadel-Turonski[1], E. Nissen[1], P. Ostroumov[2], F. Pilat[1], M. Poelker[1], A. Prokudin[1], R. Rimmer[1], T. Satogata[1], M. Spata[1], H. Sayed[12], M. Sullivan[13], C. Tennant[1], B. Terzić[1], M. Tiefenback[1], H. Wang[1], S. Wang[1], C. Weiss[1], B. Yunn[1], Y. Zhang[1]

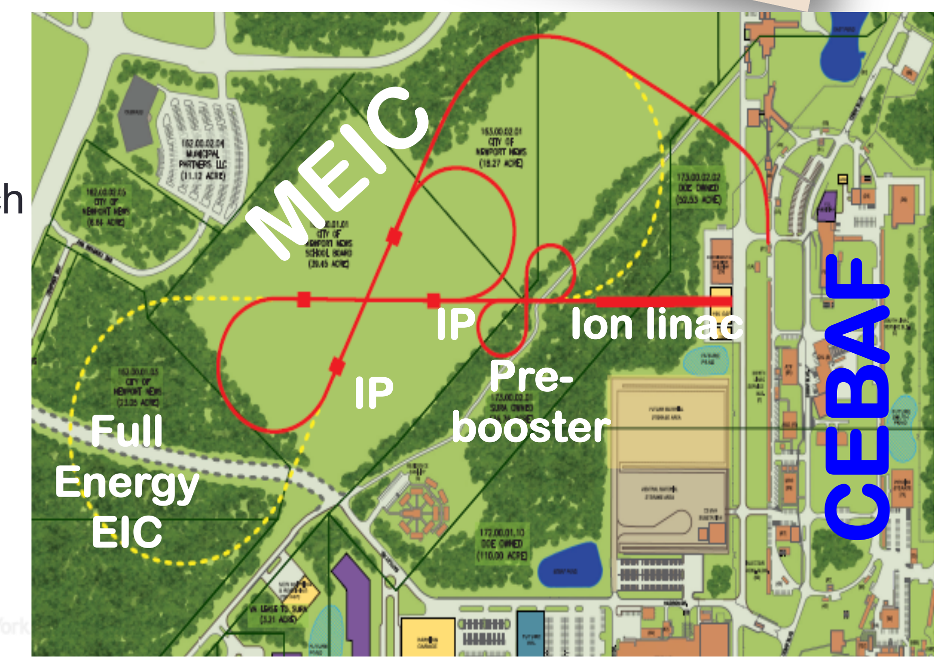
[1] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2] Argonne National Laboratory, Argonne, IL 60439, USA
[3] Catholic University of America, Washington, DC 20064, USA
[4] College of William and Mary, Williamsburg, VA 23187, USA
[5] Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg, Germany
[6] Idaho State University, Pocatello, ID 83209, USA
[7] Joint Institute for Nuclear Research, Dubna, Russia
[8] Moscow Institute of Physics and Technology, Dolgoprydny, Russia
[9] Muons Inc., Batavia, IL 60510, USA
[10] Northern Illinois University, De Kalb, IL 60115, USA
[11] Old Dominion University, Norfolk, VA 23529, USA
[12] Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[13] SLAC National Accelerator Laboratory, Menlo Park, CA 94305, USA
[14] Science and Technique Laboratory Zaryad, Novosibirsk, Russia
[15] University of Wisconsin-Madison, Madison, WI 53706, USA

Editors: Y. Zhang and J. Bisognano

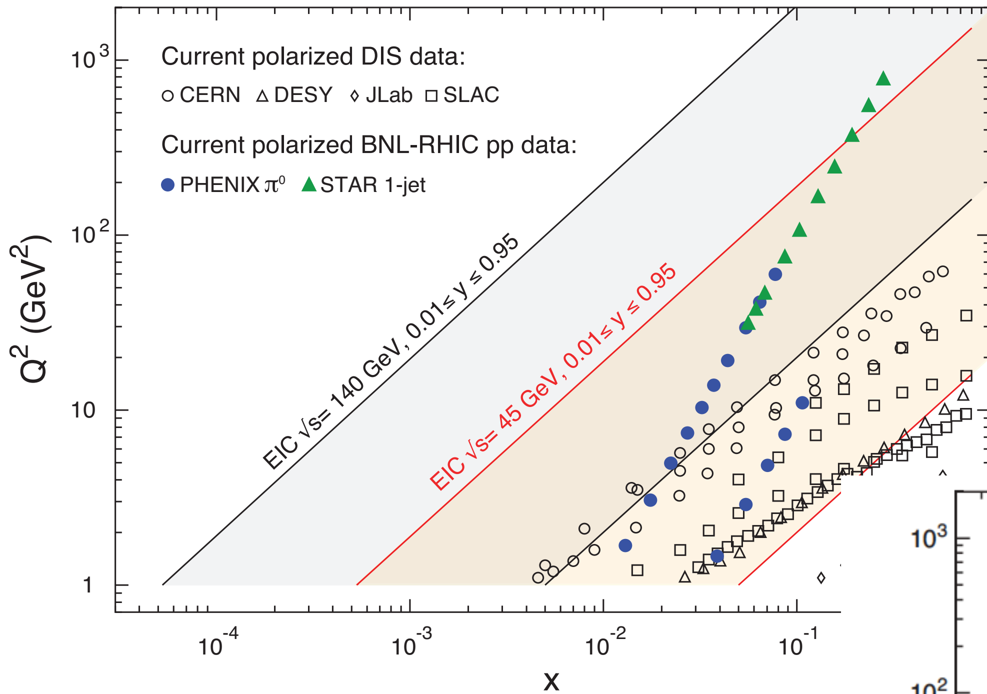
- **MEIC - a polarized medium energy electron-ion collider**
- **The MEIC baseline design**
  - A ring-ring collider, supporting 3 IPs, two for medium ion energies
  - Luminosity reaches 10^{34} cm^{-2}sec^{-1} per interaction point
  - Highly polarized electron, proton, deuteron and helium-3 beams
  - 12 GeV CEBAF recirculating linac as a full energy electron injector
  - A new ion complex consisting of source, linac and two booster rings
- **Design report released last August (arXiv:1209.0757)**
- **Now focusing on specific R&D**

  1) cooling studies – evolutionary approach
  2) dynamical aperture – 1st order o.k.
  3) polarization – tracking & optimization
  4) collective beam effects – deemed o.k.

Will add sections on cooling and polarization to existing design report



US EIC: Kinematic reach & properties

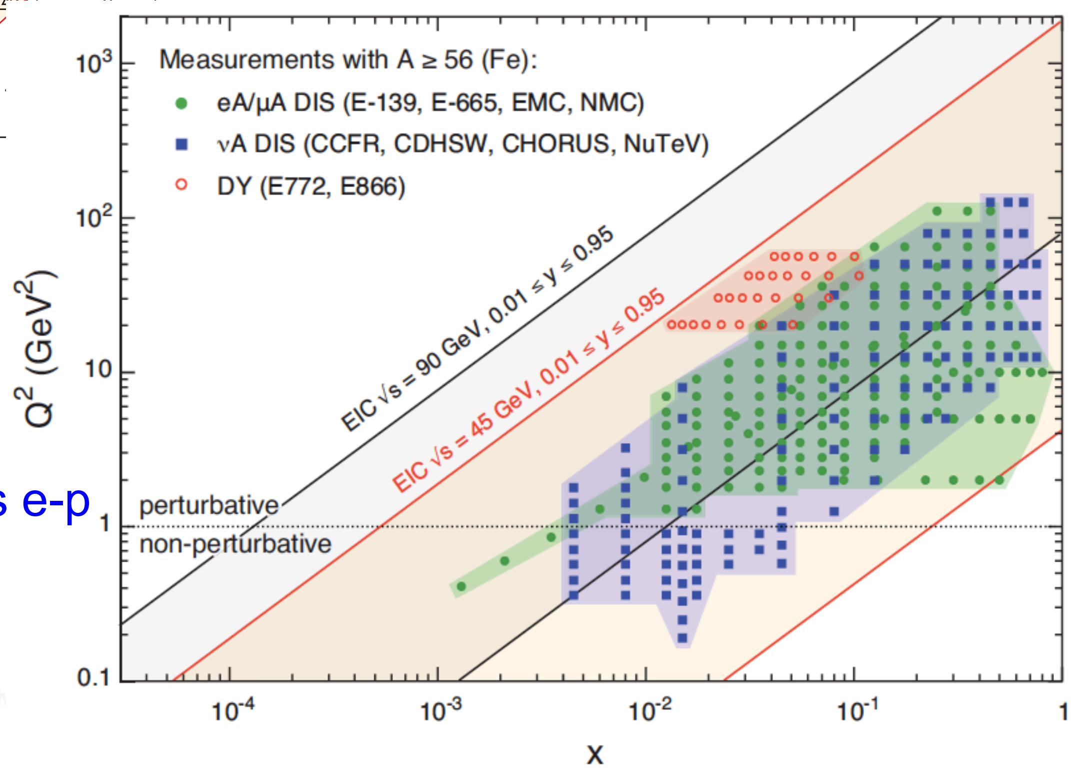


For e-N collisions at the EIC:

- ✓ Polarized beams: e, p, d/^{3}He
- ✓ **e beam 5-10(20) GeV**
- ✓ Luminosity L_{ep} ~ **$10^{33\text{-}34}$** cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ Variable center of mass energy

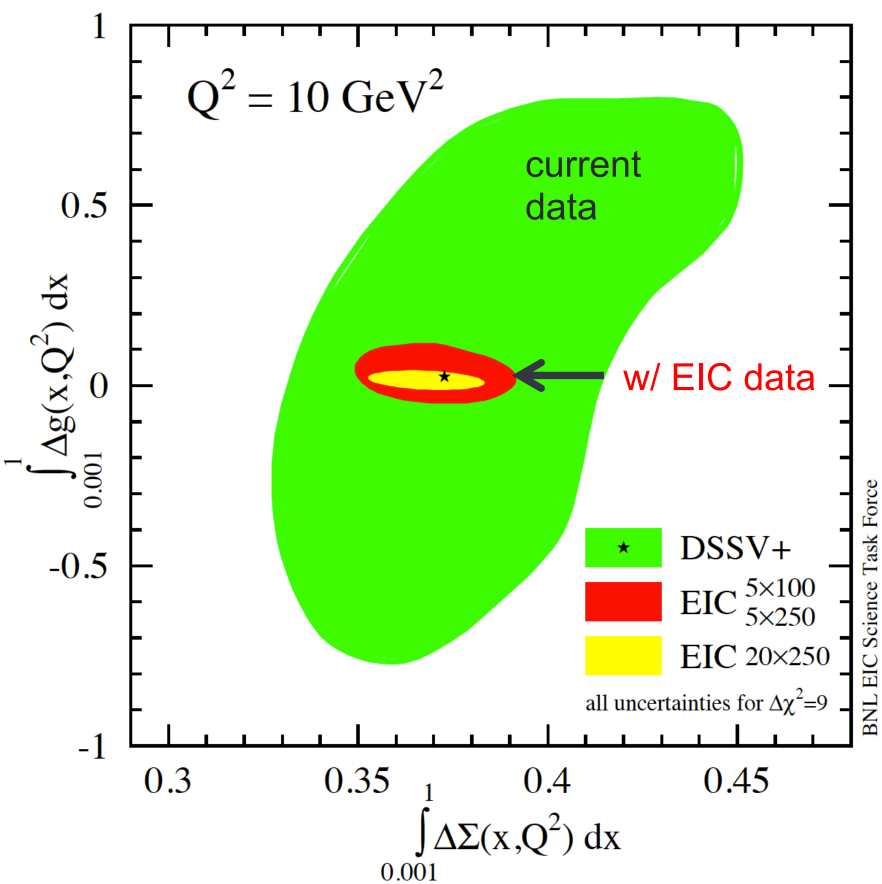
For e-A collisions at the EIC:

- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

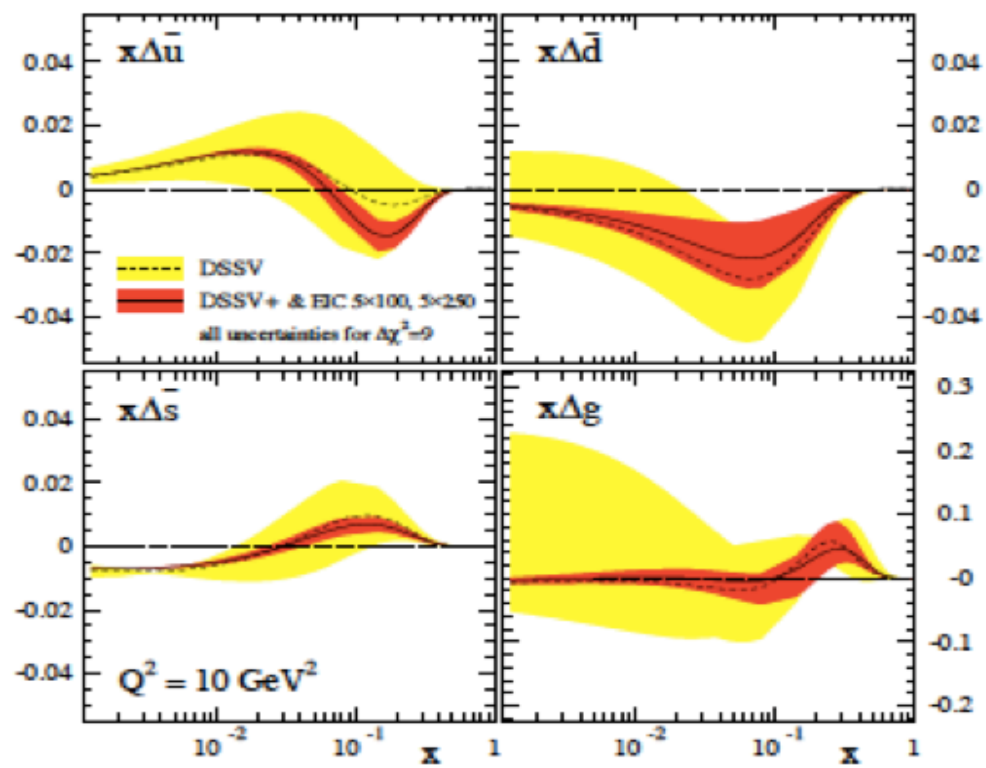


Precision: Gluon & Sea Quark *polarization:*
--Beyond the current experimental capabilities!

ΔG and ΔΣ in helicity sum

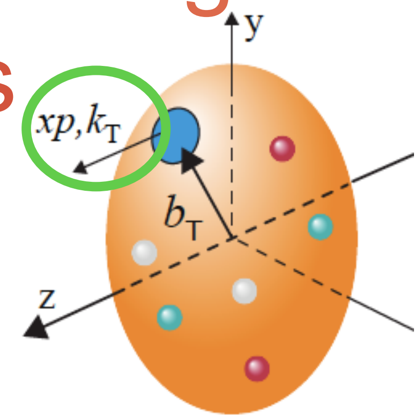


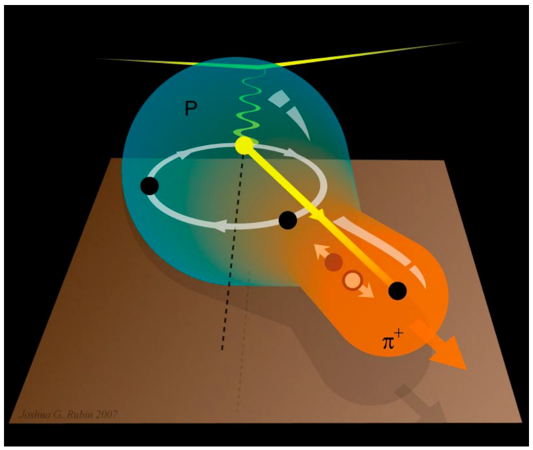
Are the sea quark polarizations different?



EIC White Paper: arXive:1212.1701

Semi-Inclusive DIS ➔ Best for measuring Transverse Momentum Distributions





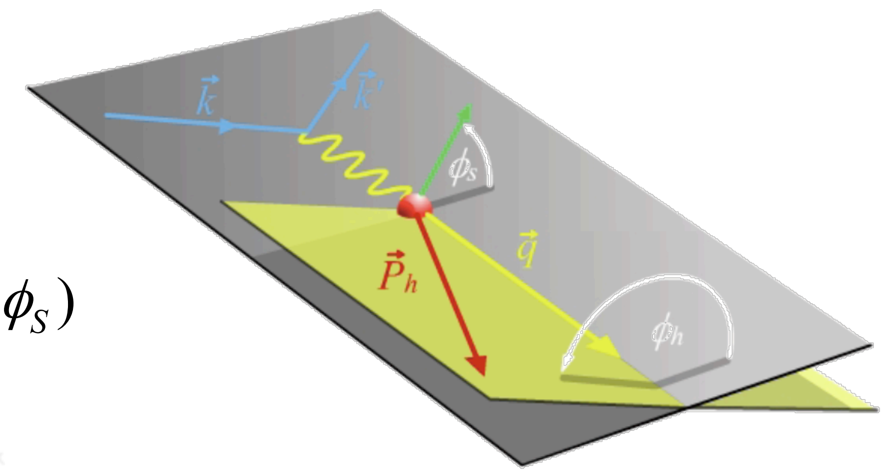
- ❑ Naturally, two scales:
  - ✧ high Q – localized probe
    To "see" quarks and gluons
  - ✧ Low p_T – sensitive to confining scale
    To "see" their confined motion
  - ✧ *Theory – QCD TMD factorization*

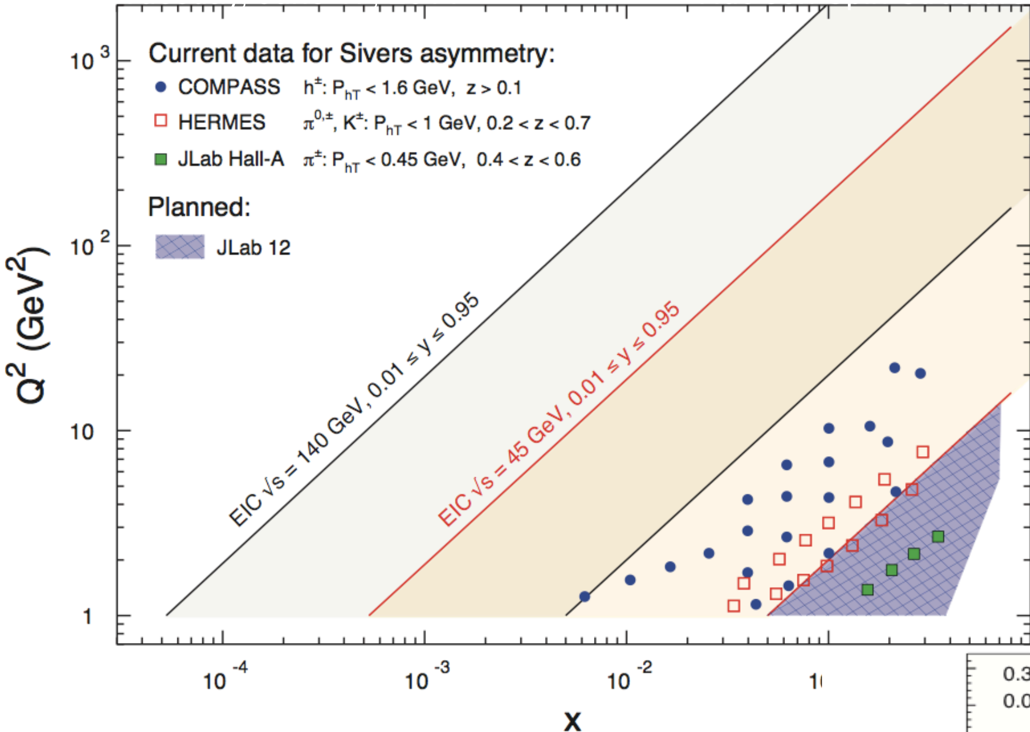
- ❑ Naturally, two planes:

$$A_{UT}(\varphi_h^l,\varphi_S^l) = \frac{1}{P}\frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

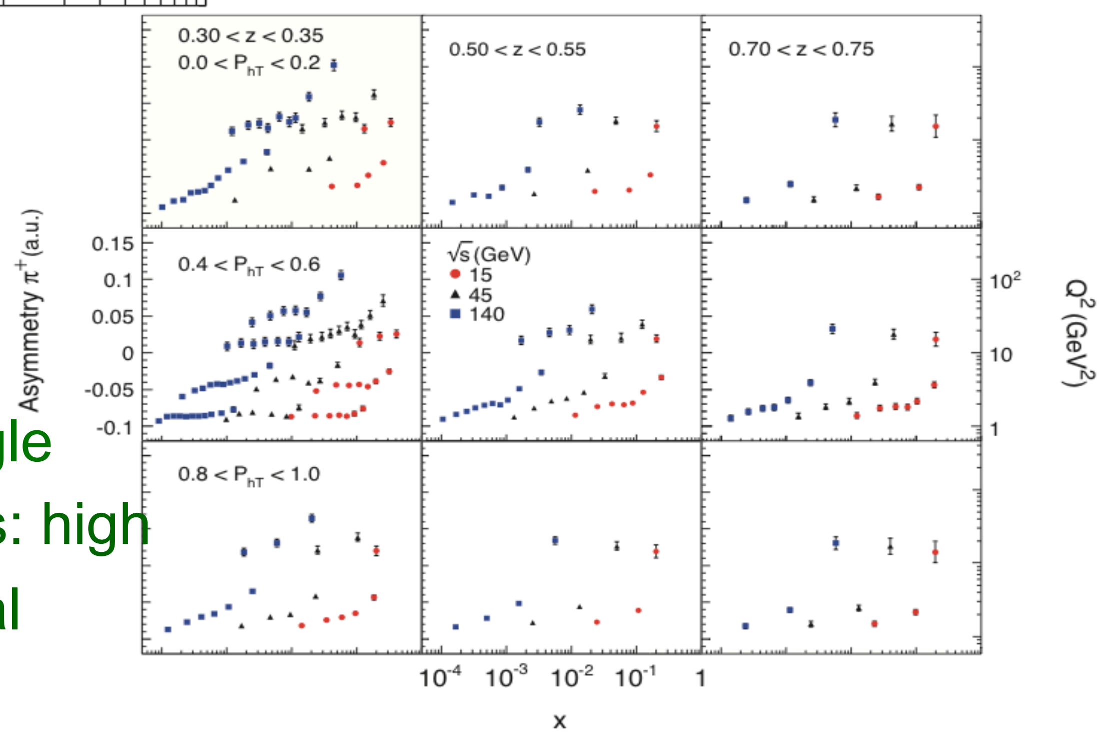
$$= A_{UT}^{Collins}\sin(\phi_h+\phi_S) + A_{UT}^{Sivers}\sin(\phi_h-\phi_S)$$

$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S)$$





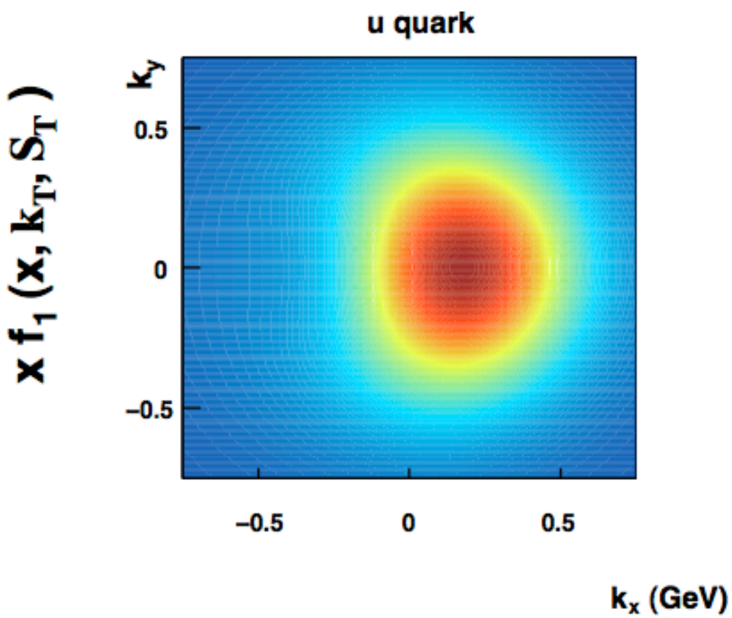
First, maybe the only, measurement of polarized sea and gluon TMDs

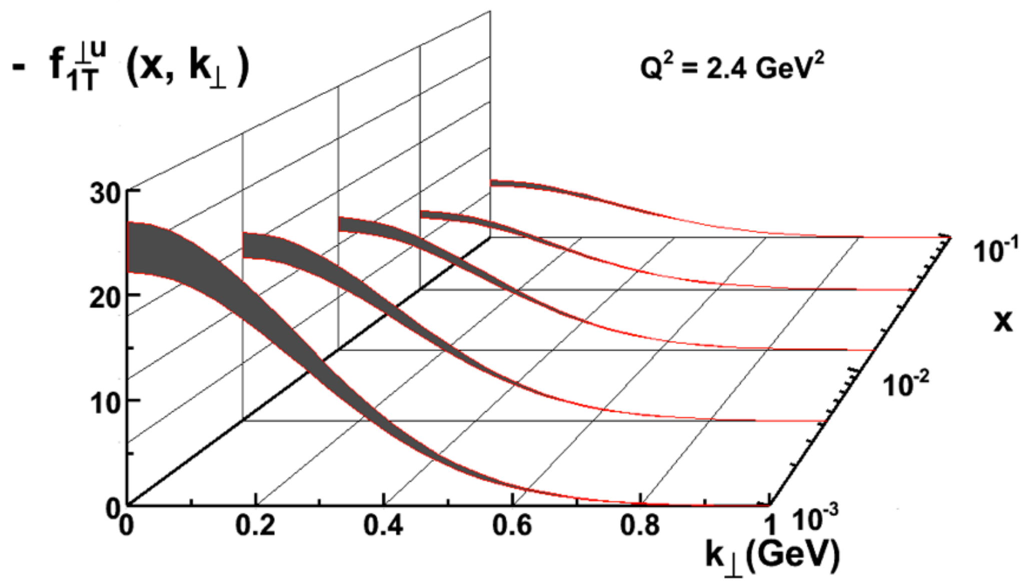


- High luminosity implies: Single transverse-spin asymmetries: high resolution & multidimensional

Momentum tomography of the nucleon

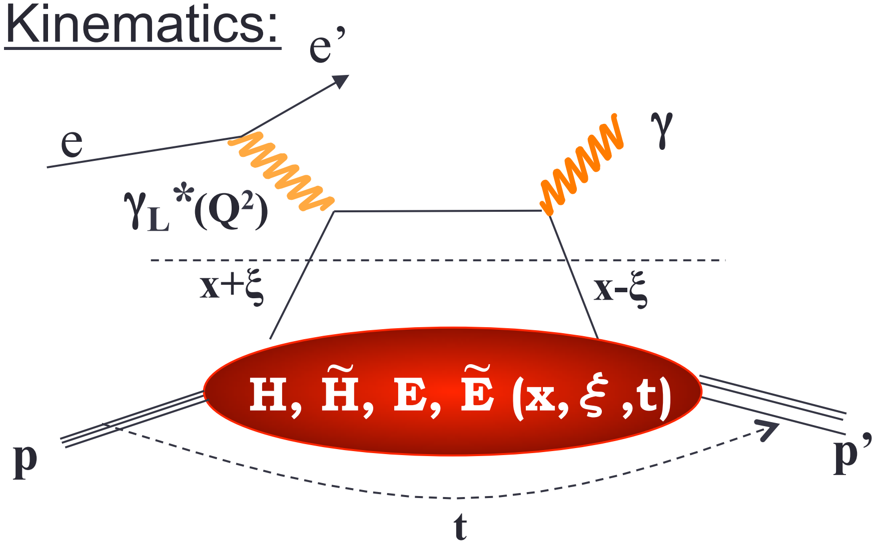
- Tomographic images of K_X/K_y of partons as functions of Bjorken-x: u quark distribution for transversely polarized proton.
- ***With EIC: low x partonic plots like these possible!***





Exclusive DIS

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e(1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$

Exclusive events:
e + **(p/A)** → e'+ **(p'/A')**+ γ / J/ψ / ρ / ϕ
detect **all** event products in the detector

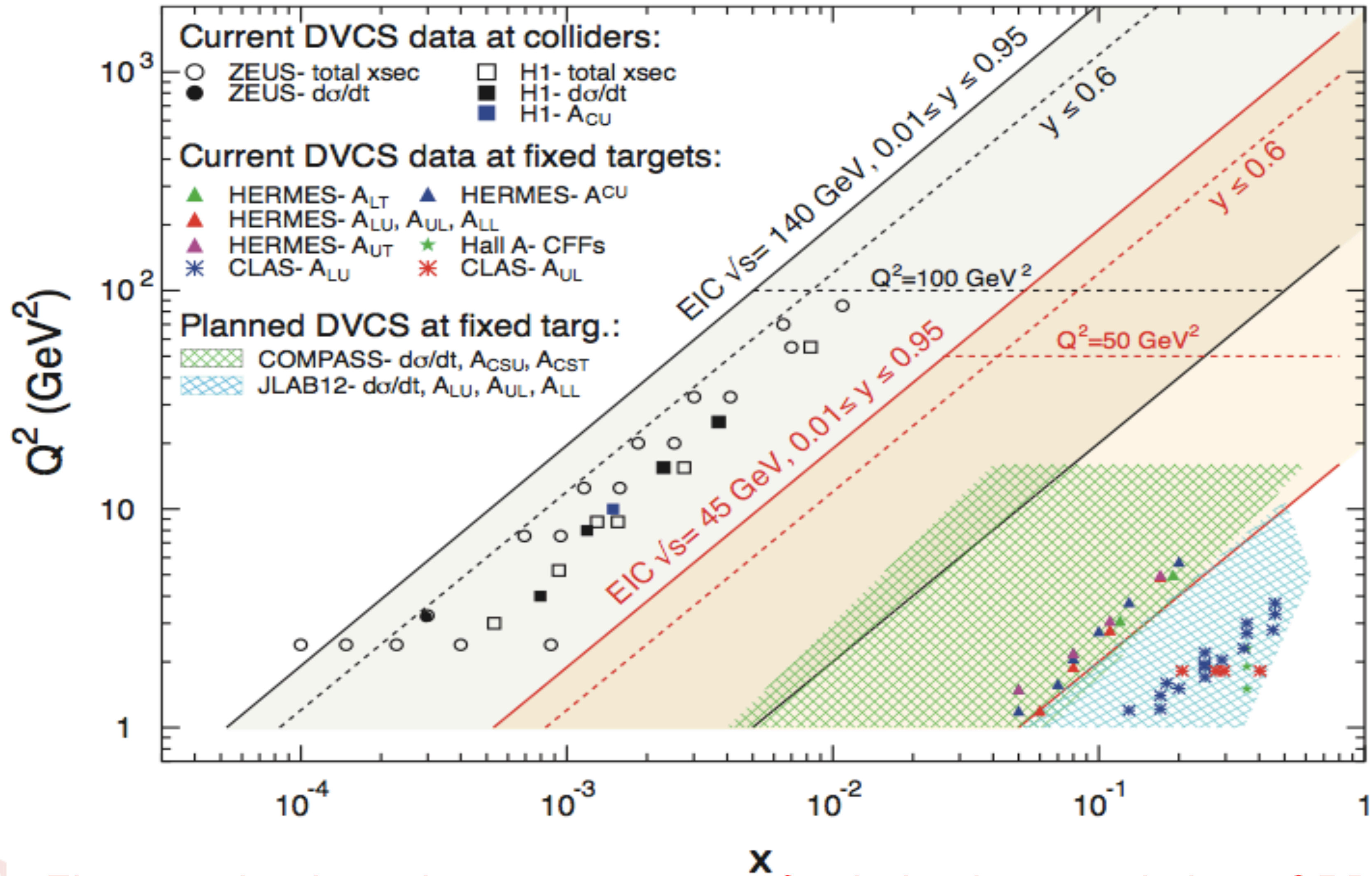
Allow access to the spatial distribution of partons in the nucleon
Fourier transform of spatial distributions → GPDs
GPDs → Orbital Angular Momenta!

$$\frac{1}{2} = J_Q + J_G$$

$$J_Q = \frac{1}{2}\Delta\Sigma + L_Q$$

$$J_G = \Delta G + L_G$$

EIC coverage for GPDs



First, maybe the only, measurement of polarized sea and gluon GPDs

GPDS: Transverse spatial gluon distribution from exclusive J/Ψ production

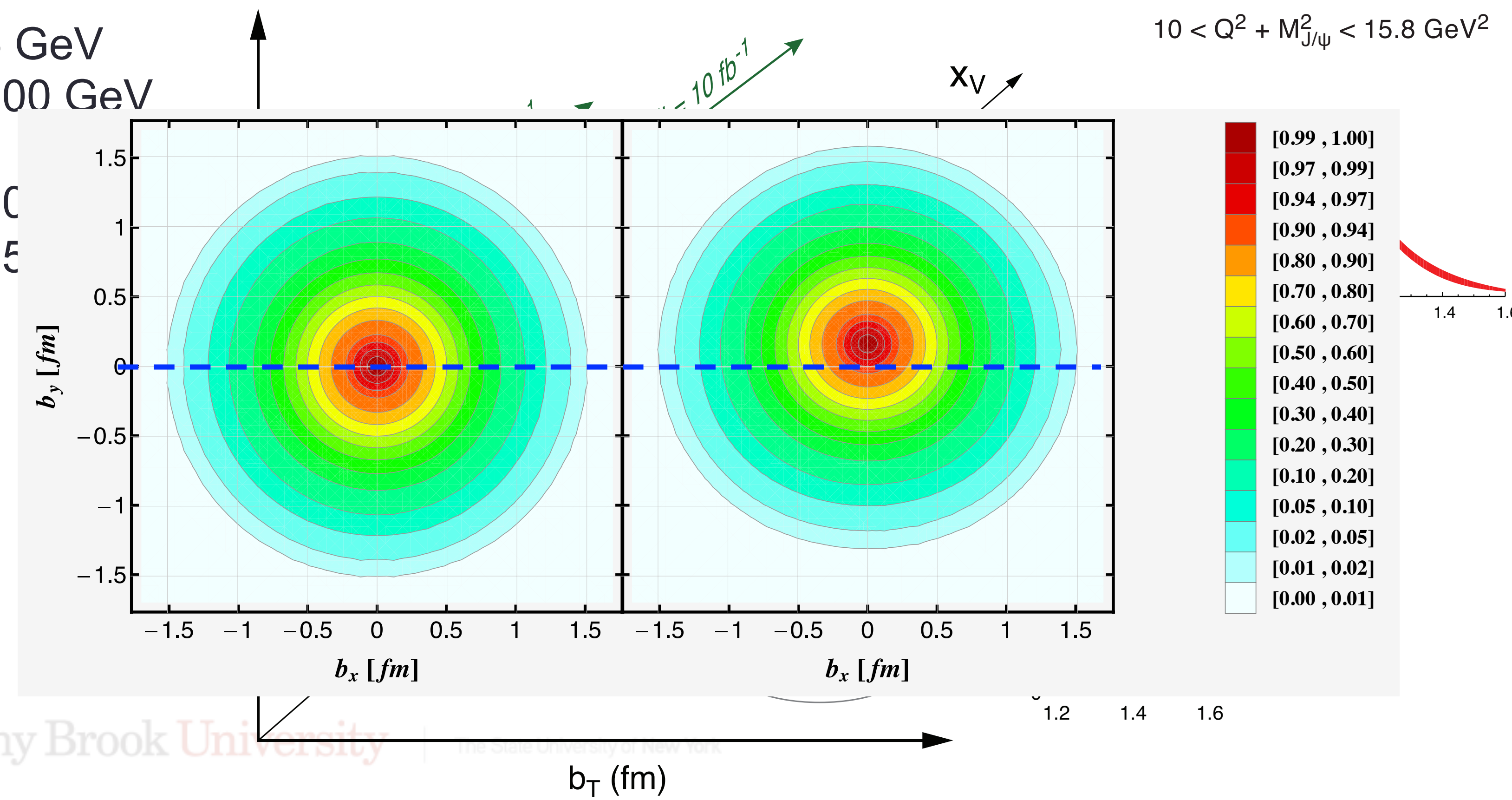
$$x_V = \frac{M_{J/\psi}^2 + Q^2}{W^2 + Q^2 + M_N^2}$$

$$W^2 = (p+q)^2; \quad M_N^2 = p^2$$

b_T is the distance of the gluon from the center of the proton
x_V determines the gluon momentum fraction

E_e = 5 GeV
E_p = 100 GeV

E_e = 20
E_p = 25



An immediate check/impact:

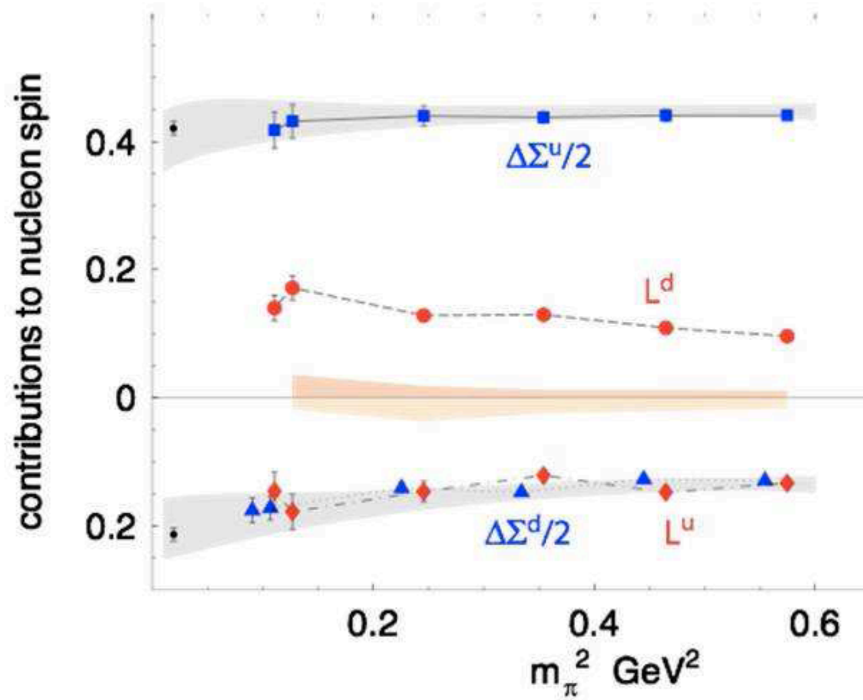
❑ Quark GPDs and its orbital contribution to proton's spin:

$$J_q = \frac{1}{2}\lim_{t\to 0}\int dx\, x\,[H_q(x,\xi,t)+E_q(x,\xi,t)] = \frac{1}{2}\Delta q + L_q$$

The first meaningful constraint on quark orbital contribution to proton spin by combining the sea from the EIC and valence region from JLab 12

This could be checked by Lattice QCD

$L_u + L_d \sim 0$?

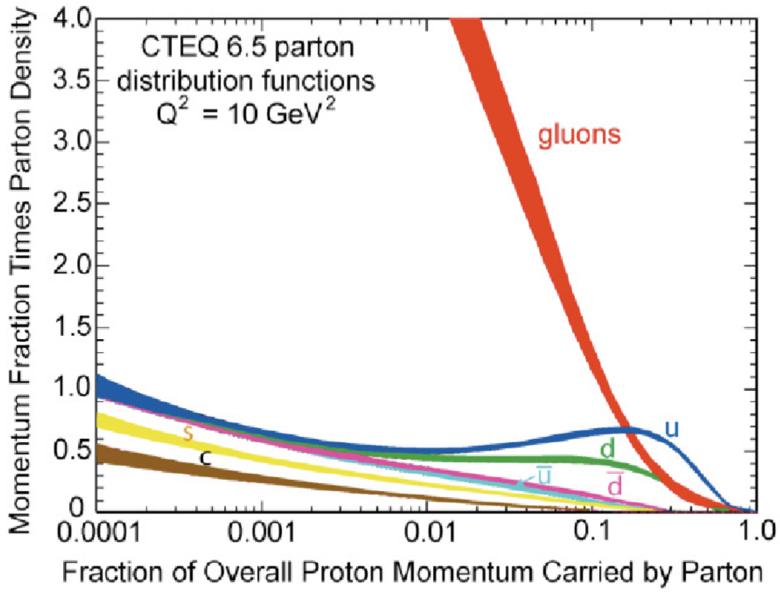


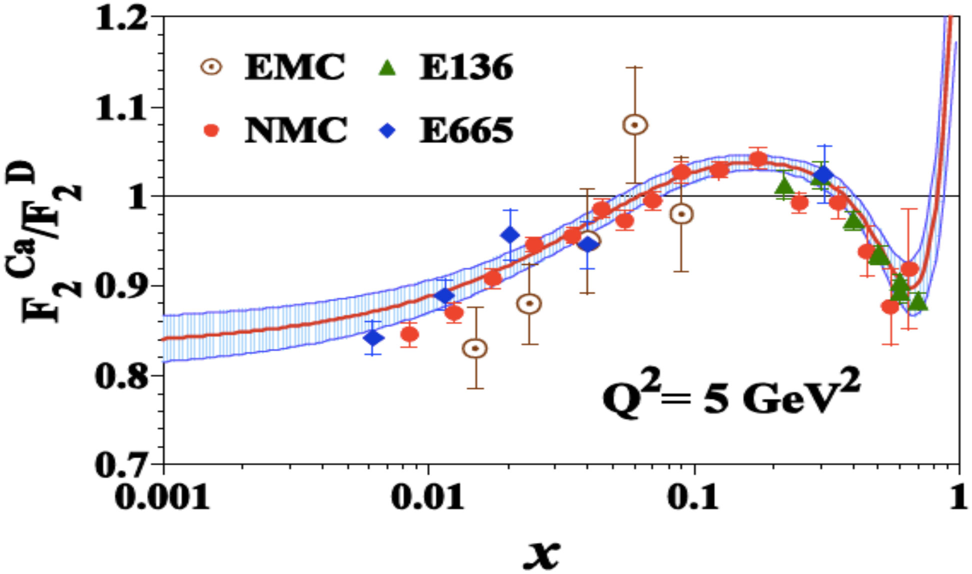
There are also more recent ideas Of calculating parton distribution functions on Lattice:
X. Ji et al. arXiv 1310.4263; 1310.7471; 1402.1462
& Y.-Q. Ma, J.-W. Qiu 1404.6860

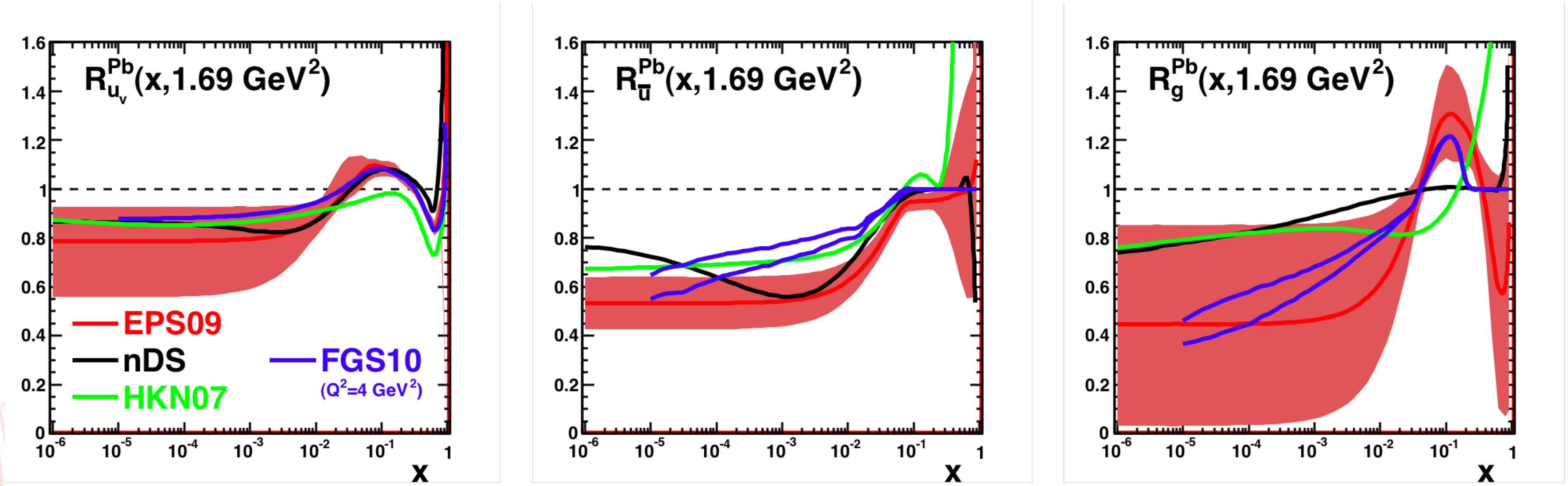
A now for something completely different! But a most exciting topic:

Physics with nuclei at the EIC!

Low-x in proton (puzzle) and nuclei (unmeasured)





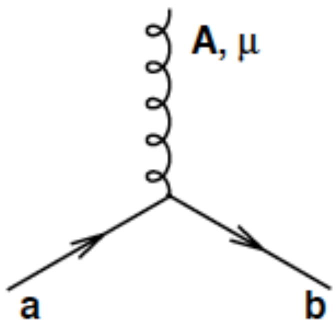


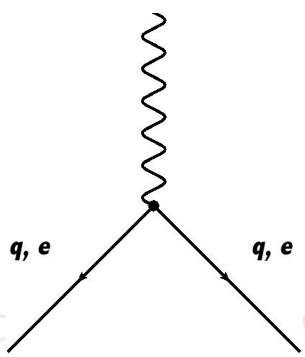
What distinguishes QCD from QED?

QED is mediated by photons (γ) which are charge-less

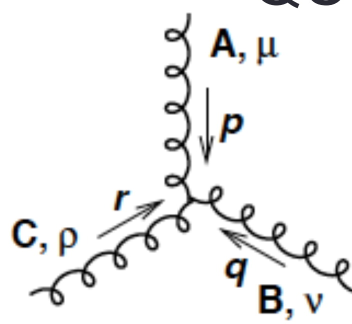
QCD is mediated by gluons (g), also chargeless but *are* colored!

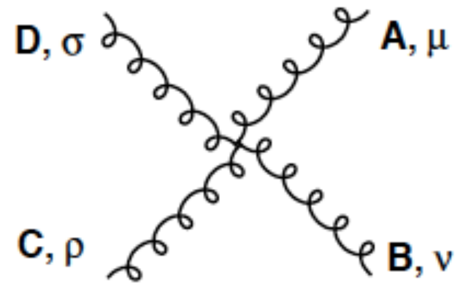
In QCD &
g → γ in QED



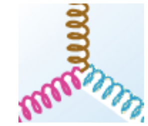


Only in QCD





Gluon self-interaction in QCD

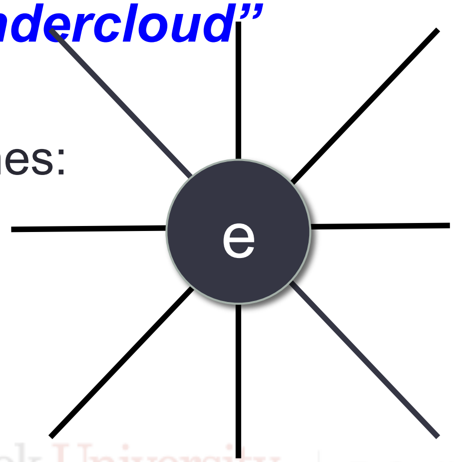


Dynamical generation & self-regulation of hadron masses

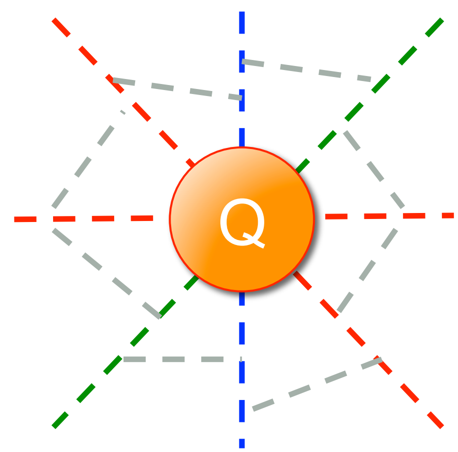
F. Wilczek in "Origin of Mass"

*Its enhanced coupling to soft radiation… means that a 'bare" color charge, inserted in to empty space will start to surround itself with a cloud of virtual color gluons. These color gluon fields themselves carry color charge, so they are sources of additional soft radiation. The result is a self-catalyzing enhancement that leads to a **runaway growth**. A small color charge, in isolation builds up a big color thundercloud….**theoretically the energy of the quark in isolation is infinite… having only a finite amount of energy to work with, nature always finds a way to short cut the ultimate thundercloud"***

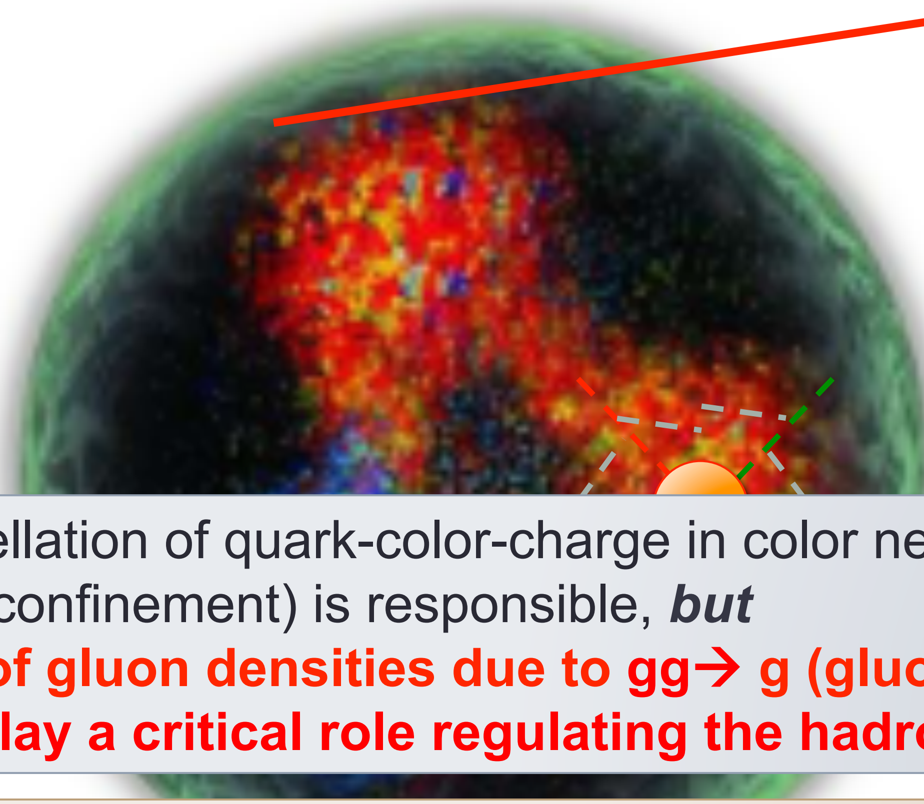
Electric charge, lines: photons

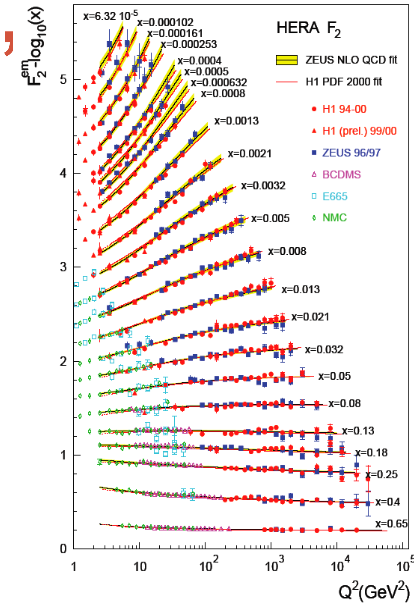


Color charge gluons



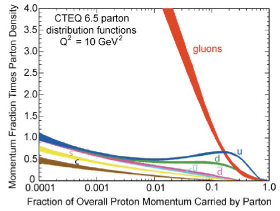
What limits the “thundercloud”





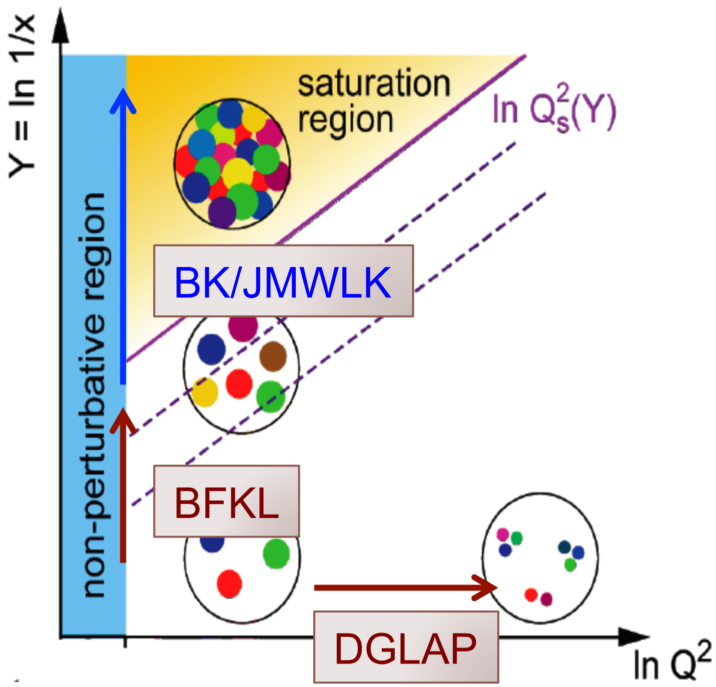
- Partial cancellation of quark-color-charge in color neutral finite size of the hadron (confinement) is responsible, ***but***
- **Saturation of gluon densities due to gg→ g (gluon recombination) must also play a critical role regulating the hadron mass**

Need to experimentally explore and study ***many body dynamics***
a) regions of ***quark-hadron transition*** and
b) non-linear QCD regions of extreme ***high gluon density***



Physics at Low x?

See Ann. Rev. Nucl Part (60) 2010 F. Gelis et al., , arXiv:1002.0333)

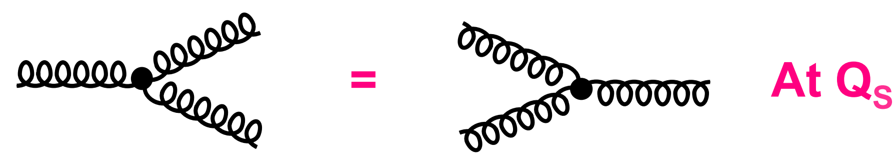


Method of including **non-linear** effects (McLerran, Venugopalan)

- Small coupling, high gluon densities
- BK/JMWLK equations lead to a Saturation Scale $Q_S(Y)$

Linear QCD
BFKL: gluon
emission

Nonlinear QCD
BK/JMWLK gluon
recombination



Strongly correlated gluonic system? Universal? Properties?

Need a higher energy e-p collider than HERA! ➔LHeC

Or ➔ Nuclei: naturally enhance the densities of partonic matter

Why not use Nuclear DIS at high energy?

Saturation/CGC: What to measure?

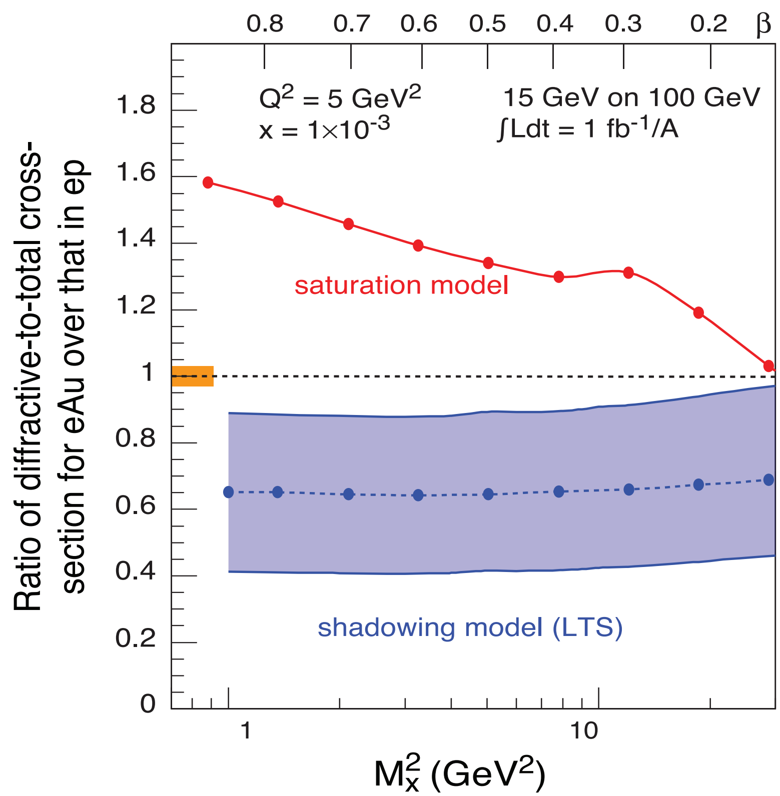
- F_2 (quark+ antiquark) & F_L(gluons) at low x (classic inclusive measurement)
  - $g(x,Q^2) \propto \frac{\delta F_2}{\delta \ln Q^2}$ $\qquad F_L(x,Q^2) \propto g(x,Q^2)$
  - F_L requires change in the center of mass energy in operation of collider

Diffraction:

$$\sigma_{\text{diff}} \propto [g(x,Q^2)]^2$$

At HERA: ep observed 10-15%
If CGC/Saturation: then
Diffraction eA expect ~25-30%

Diffractive to Total cross section ratio for eA/ep

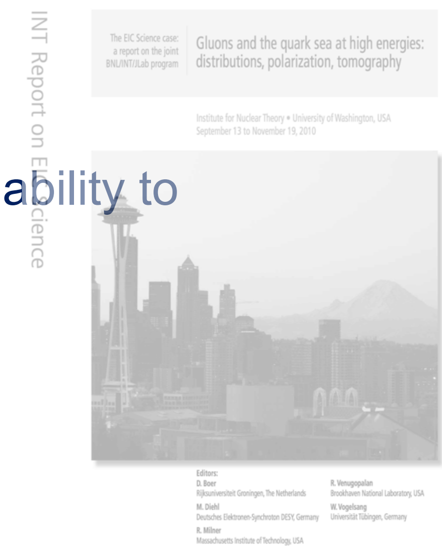


Experimental challenges in diffractive measurements drive the detector and IR design.

Evolving status of EIC in the US:

❑ NSAC 2007 Long-Range Plan:

"An **Electron-Ion Collider (EIC)** with **polarized** beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia."



❑ NSAC Facilities Subcommittee (2013):

The Subcommittee ranks an EIC as **Absolutely Central** in its ability to contribute to world-leading science in the next decade."

❑ NSAC NEXT Long-Range Process:

Officially started! Final report due on October 15, 2015
EIC needs to be a high recommendation in this report!

EIC User Group Meeting at Stony Brook (June 24-27, 2014)
http://skipper.physics.sunysb.edu/~eicug/meetings/SBU.html

Summary & Outlook:

RHIC, the first polarized collider, has been a huge success: high impact results on gluon and anti-quark polarizations and emergent transverse spin phenomena

The Electron Ion Collider will further bring new "dimension" to our understanding of nucleon spin: from 1D → 2+1D tomographic images of nucleon may be possible… (and an exciting program with nuclei)

EIC: 1st *polarized* DIS collider, 1st nuclear DIS collider, ***Focus: QCD***

- ***Precision studies of the role of GLUONS & SEA QUARKS in QCD***

Currently two designs: JLab & BNL both use upgrades of existing facilities**.**

Next milestones for US EIC: Long Range Plan of the NSAC 2014/5 for support & approval by the US NP community. ***Its critical that both JLab and RHIC user communities work closely together with our international collaborators to get this approved through the LRP.***

Development of the Standard Model of Physics needed: **p-p/p-bar, e-e, e-p** collisions →**complimentary** but **essential** role

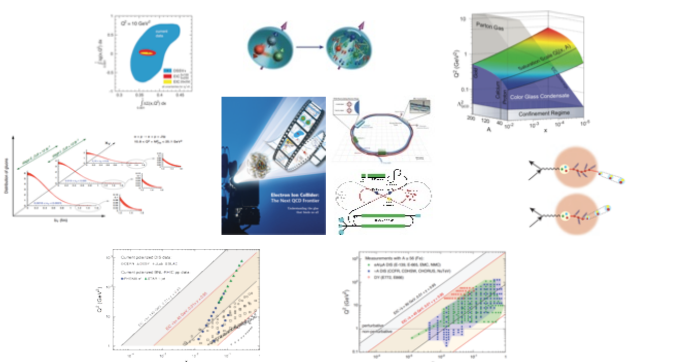
- **EIC's** will add "**spin**" and "**nuclei**" to this list: A-A, p/d-A, **e-A** to study QCD

EIC Users Meeting at Stony Brook: June 24-27, 2014
http://skipper.physics.sunysb.edu/~eicug/meetings/SBU.html

SBU Scientific Program Parking Conveners Registration Housing Organization Sponsors Participants Documents & Links

Electron Ion Collider Users Meeting

June 24-27, 2014 at Stony Brook University



Venue:
Hilton Garden Inn & the Wang Center at Stony Brook University
Travel to Stony Brook & Maps etc.
Logistics: Arrival & Parking

Meeting:
Registration
Registered Participants
Housing (open)
Scientific Program
Organizers
Sponsors

Administrative Support/Contact:
Ms. Socoro Delquaglio
Department of Physics & Astronomy
Tel: +1 (631) 632-8757
socoro.delquaglio_at_stonybrook.edu

Motivation & Goal of this meeting:

In 2013 the Nuclear Science Advisory Committee's subcommittee on Future Facilities called the Electron Ion Collider (EIC) "*central to the US nuclear science program in the coming decade and beyond*". In anticipation of the US nuclear science community's next long range planning (LRP) exercise in 2014/2015, this meeting of the potential EIC users is aimed at initiating the discussions and planning needed to get the EIC recommended by the NSAC as the next major facility in nuclear science in the US. All interested in seeing the EIC realized are invited.

Significant progress has been made in the last few years on:
a) defining the science case for the EIC
(INT program proceedings & the EIC White Paper)
b) the technical design of the collider
(Presentations at the EIC Advisory Committee meeting)
c) detector design ideas for both the BNL and at JLab machine designs made possible by *the influx of R&D funds for detector.*

In this meeting we will present the status of machine designs, the science case, and the detector ideas & technologies currently under consideration. We welcome new ideas from the potential EIC users. We will explore opportunities for collaborations amongst national and international participants across various boundaries.

EIC in the context of:
US Nuclear Physics Long Range Plan
US Nuclear Science
The International Context

Student lectures,
Presentation: Science of EIC, White Paper,
Discussion sessions on
physics and future collaboration

Registration closed but if still want to attend, please come talk to me after this talk